HAWAII AGRICULTURAL EXPERIMENT STATION.

J. G. SMITH, SPECIAL AGENT IN CHARGE.

BULLETIN No. 11.

THE BLACK WATTLE

(*Acacia decurrens*)

IN HAWAII.

BY

JARED G. SMITH,

SPECIAL AGENT IN CHARGE,

HAWAII AGRICULTURAL EXPERIMENT STATION.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

Honolulu, Hawaii, *January 1, 1906.*

Sir: I have the honor to transmit herewith a paper on The Black Wattle in Hawaii and recommend the same for publication as Bulletin No. 11 of the Hawaii Agricultural Experiment Station.

Very respectfully,

Jared G. Smith,
Special Agent in Charge,
Hawaii Agricultural Experiment Station.

Dr. A. C. True,
Director, Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. True,
Director.

Publication authorized.
James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

THE BLACK WATTLE IN HAWAII.

INTRODUCTION.

The Australian black wattle (*Acacia decurrens*) has been in cultivation in Hawaii for about forty years, trees of about that age existing in the Hamakua and Kohala districts on Hawaii. This leguminous tree reaches its fullest development in these islands. It grows on a variety of soils, but thrives best on rather heavy soils at an elevation of from 800 to 3,000 feet above sea level, in districts where the rainfall ranges from 80 to 150 inches per annum.

In January, 1905, the Hawaii Experiment Station commenced to harvest the tan bark from a 6-acre grove of black wattle situated at the lower edge of the Tantalus forest. The trees were growing on a very steep slope at an elevation of from 600 to 800 feet above sea level. The grove had been planted about thirteen years. In addition to about two tons of bark, which was shipped to various tanneries in the United States for experimental use and for which no charge was made, 36 tons of bark were sold, realizing $839.44. Besides the tan bark, 500 fence posts and 88 cords of firewood were obtained. The firewood was sold for $689.25, so that the total value of this grove of black wattles amounted to over $1,600. The total yield per acre was valued at $254.84, of which $139.97 was for tan bark and $114.87 for firewood. The wood averaged $7.83 per cord and the bark $23.31 per ton.

During the period from 1888 to 1893 there was a great deal of interest taken in wattle planting in Hawaii. At that time there was a shortage of European tanning materials, which resulted in a good deal of activity tending toward the substitution of new tanning materials for the valonia oak. Tan bark doubled or trebled in price and many persons not only here in Hawaii but in Australia and South Africa looked upon wattle growing as a very promising method of quickly achieving large profits. A considerable amount of seed was secured and distributed throughout the islands, so that now there is hardly a district where full-grown specimens of this tree can not be found. Although forest planting was advocated, apparently the only forest planted was that on the Tantalus ridge. The occurrences of

1893 and subsequent years diverted public attention entirely from the development of this and other minor industries to the more immediately profitable sugar industry, and no extensive planting of this tree was made.

During the twelve years from 1893 to 1905, the trees in the Tantalus forest had reached their full development. During the four years that this station has had possession of this portion of the forest about 20 per cent of the wattle trees died from various causes, not only because many of the trees had reached their limit of growth, but on account of injury from stock and by insects. It was therefore deemed advisable to harvest the trees and endeavor to make as much out of them commercially as possible, in order to demonstrate something of what might be obtained in the way of returns, provided this tree were to be planted on a commercial scale.

Almost everybody in Hawaii is fully convinced that it would be well from the æsthetic point of view as well as the practical to extend the area of forests. The value of forests is well recognized for water conservation and to a greater or less extent as a source of firewood. However, little thought has thus far been given to planting trees which will not only make a forest cover but will yield a good investment on the money spent for planting the trees and for caring for them during the early years, when they require more or less care.

It is believed that by planting tan-bark trees, especially the black wattle, the cash values obtainable at the end of a given period will yield a large return of profit. It is furthermore believed that trees or plants yielding tannin will supply a product of increasing rather than decreasing value. The natural resources of tannin are becoming depleted in Europe and the United States.

It is a matter of interest that at no time during the last fifteen years has the price of wattle bark fallen to less than $20 per ton. The average price in Natal, which country produces the bulk of the world's cultivated supply, has ranged from $29 to $35 per ton during the last five years.

CULTIVATION.

If the land to be devoted to wattle cultivation is level or reasonably so, it would be best to plow it. Of course gulch and mountain land or broken slopes are not capable of being plowed. If the land is plowed, it should be allowed to rest for three to six months, and should then be harrowed and cross-plowed. One pound of good seed will plant 10 acres.

The seed is covered with a very hard skin, and when placed in the ground without previous treatment germinates slowly. Two methods of improving the germination of the seed are in vogue. The safer method is to put the seed in a bucket and pour boiling water upon it

and allow it to stand for twenty-four hours. The other method is to scorch the seed in hot ashes by building a fire, allowing the wood to burn until there is a bed of coals, then rake off the coals and mix the seed with the ashes beneath. This latter method requires some judgment, as the seed should not be parched, but only scorched.

It is more economical to plant the seed in the place where the tree is to remain than to plant in nursery rows and transplant. The seed should be sown in rows 10 feet apart and 2 or 3 feet apart in the row. If the ground has been plowed, the young seedlings should be cultivated, and this can best be done by planting some secondary crop, such as corn, potatoes, cotton, or tobacco, between the rows during the first two years. Where two or three seedlings come up in one place they should be thinned, leaving only one plant about every 6 feet. If gulch lands are chosen for planting, holes 3 feet in diameter should be dug at intervals of 6 by 10 feet, and the holes should be filled up with top soil mixed with weeds or grass and the seed planted in the holes thus formed.

A forest which is given the benefit of two or three years of cultivation, as would be the case if an intermediate crop were grown between the rows, will make far better and more rapid growth than trees simply set out on uncultivated land. The value of the intermediate crop would also offset the cost of planting the forest. After the third year the trees will be large enough to take care of themselves, and, if planted close, will so shade the land that weeds and grasses can not grow. The chief enemy of a forest of this character is fire. On that account it is better, if a large acreage is set out, to plan fire lanes or avenues between the forest blocks, so that the soil in these fire lines may be plowed and kept bare of weeds and grasses. If the acreage is sufficiently large to warrant it, practically all the operations of sowing the seed and cultivating the land may be done with horses. One man with a good team and riding plows and cultivators ought to be able to take care of 250 acres of trees per working year of three hundred days; that is, plow the land, sow the seed, and cultivate the seedling trees. However, if an intermediate crop is grown between the rows during the first three years the amount of land one man can cultivate will be somewhat less.

HARVESTING.

The trees should be ready to cut in about ten years, the period of maturity varying with the character of the soil and the amount of rainfall. Trees of equal age in the Tantalus forest varied from 18 inches at the butt when growing on rich soil with heavy rainfall to only 6 inches in diameter on rocky, thin soil at a lower and drier elevation. Trees 10 years old, if properly grown, should yield at least 100 pounds of green bark, equal to 50 pounds of dried bark. Trees which have

grown in especially good soil or under exceptionally good conditions even yield as high as 200 pounds of green bark, while those from drier and more sterile soil yield so little that it hardly pays to strip the bark. Hence it is the opinion of the author that while this tree is said to be one of those suited for even the most sterile soils, yet it is doubtful whether the black wattle can be profitably cultivated except on land of fairly good character. (Pl. I.)

Harvesting consists in cutting down the trees and stripping off the bark. (Pl. II.) In Natal, where this tree is cultivated on a very large scale, most of the bark is stripped from the tree while it is still standing. The laborer makes a cut as near the ground as he can, pries up a loose end of bark, and then jerks it loose from the tree, removing in this way a strip perhaps 6 inches wide and from 10 to 30 feet long. After the laborer has stripped all the bark that he can in this way the tree is cut down and the remainder of the bark secured. It is yet to be determined in Hawaii which is the more profitable method of harvesting the bark—whether it is better to cut down the tree and take the bark off after it is felled or whether it should be stripped from the standing trunk. The bark does not strip well in dry weather, but requires closer attention to prevent it from molding in wet weather.

During the drying process the bark must be carefully protected from rain. This is fully as important a point as the selection of good soil or care in cultivation, because bark which has been allowed to get wet after it is taken from the tree becomes of only secondary value. For the purpose of drying the bark large sheds or barns should be erected at some convenient location, such as the lowest point of the land, provided it is near to roads. In South Africa the drying sheds are rather small. The bark is hung up on poles, the ends of which fasten in rings on long chains suspended from a scaffolding. When fully extended this arrangement of chains and poles might be compared with a large rope ladder. During clear weather the contrivance is extended full length out of doors. When rain threatens, the whole arrangement of poles and chains is drawn back under the shed, shutting up like the folds of a bellows. (See Pl. III.)

There is considerable difference of opinion in regard to what makes bark of a good quality—that is, whether that which is dried in the sunlight or in the shade is of the better quality. It has been found in Hawaii that bark dried under roofs and not exposed to the sunlight at any time during the drying process was of the best color and brought the highest price. The main point is to dry it in such a manner that it will not mold. A high temperature should also be avoided.

A number of experiments have been made to determine the best and most convenient way of getting the bark out of the woods. If the drying shed is at the lowest point of the forest the bark can be bun-

STRIPPING TAN BARK FROM BLACK WATTLE TREES, HAWAII EXPERIMENT STATION.

BLACK WATTLE TREES GROWING ON STERILE, ROCKY SOIL, HAWAII EXPERIMENT STATION.

FIG. 1.—THE DRYING SHED, WITH ITS RUNWAYS FOR THE POLES.

FIG. 2.—THE RUNWAYS, WITH THEIR CHAINS AND POLES.

A NATAL DRYING SHED.

Photographs by Mr. David Fairchild, agricultural explorer, U. S. Department of Agriculture.

dled and sent down to the drying sheds on wire trolleys; or if there is a sufficiently large acreage to make it worth while a portable track can be laid through the lanes and fire lines between the forest blocks and the bark loaded upon cars and sent down to the drying sheds under some sort of a gravity system. Where the bark is dried in strips, either hung from poles on the rings of a ladder-like contrivance or on wires or poles underneath a galvanized-iron roof, it has been found that a good deal of labor is required that might be done away with provided drying sheds of a little more expensive nature were constructed. The bark is cut a good deal easier when green than when it is dried. Green bark even from the butts of large trees can be cut with an ordinary feed cutter worked by a gasoline engine of low horsepower. The dried bark, on the contrary, requires special bark-cutting machinery. In the author's opinion, it would pay to build a large drying house, carrying the structure up from 30 to 50 feet and providing permanent scaffolding to carry temporary floors constructed of expanded or perforated metal or of slats placed 1 inch apart, the floors not over 18 inches apart. As fast as the green bark is received at the drying house it could be run through power cutters, chopped into lengths of 2 or 3 inches, and distributed uniformly over the perforated floors, beginning at the bottom of the house. A layer of chopped bark 3 to 6 inches deep will dry without molding, provided there is a water-tight roof over the building and good ventilation supplied. Artificial ventilation with low heat could be provided for drying the bark during the periods of rainy weather, while on clear days the ventilators and sides of the building could be opened up, allowing free access of air.

As labor is the expensive item in all agricultural operations, it will pay to put in a good plant wherever the area of forest amounts to over 1,000 acres. When the cut bark is thoroughly dried it can be compressed into bales of two or three hundred pounds weight, covered with burlap, and in that shape can be shipped or transported to any distance. If a plant is to be erected for working the wood as well as the bark, the woodworking and tan-bark drying establishments should be combined.

INFLUENCE OF CLIMATE ON TANNIN CONTENT.

Little is known in regard to the influence of climate upon the production of tannin, although it is usually assumed that plants grown in an arid or semiarid region contain more tannin than those grown where there is an abundant rainfall. Analyses of koa bark (*Acacia koa*) from trees above Hilo showed 17 per cent of tannin, while samples taken from trees growing on the mountains above Hoopuloa, in Kona, a much drier district, showed only 12 per cent. It is quite probable that the presence of large amounts of tannin in the roots,

bark, leaves, or other parts of plants is an inherent characteristic due to the species and not to the climate. Samples of wattle bark taken from trees growing in very wet districts in Hawaii show fully as high tannin content as the bark of trees growing in the very dry districts. A series of analyses made by the chemist of this station showed a range of from 25 to 36 per cent of tannin present. Furthermore, there was no apparent relation between the tannin content and the soil or season. It is therefore safe to say that the highest yield of tannin per acre can be secured from lands on which the trees during their normal growth will produce the largest amount of bark, and, presumably, the largest amount of bark will be produced on trees growing where the soil is good and the rainfall sufficiently heavy so that the tree will make an uninterrupted growth. The larger the tree the more bark, the more bark the more tannin, and, commercially, the higher the value.

Wattle bark is one of the principal agricultural exports from the British colony of Natal, in South Africa. About 12,000 tons, valued at an average price of from $30 to $34 per ton, are exported each year. The larger portion of this bark is shipped to England, but a portion is marketed in Italy. Its value in Europe averages about $45 per ton, so that ocean freights, commissions, and selling charges constitute about one-third the value of the bark when it reaches the European market.

TAN-BARK EXTRACTS.

Besides the amount of bark shipped, a considerable quantity is converted into extract, and in this form some of it reaches the American market. Tannin extract is a concentrated diffusion of the green or dried tan bark in water. If green bark is used, the bark and twigs and even the younger branches of the tree are finely macerated, extracted with water by the diffusion process, and the extract boiled down in copper vacuum pans at low heat, filtered, bleached, and purified. When the extract has been concentrated to about the consistency of thick tar it is run into casks and is then ready for marketing. Liquid extracts contain as low as 20 per cent of tannin and as high as 50 per cent, while the solid extracts contain from 50 to 70 per cent of tannin. The price per pound on the American market varies with the tannin content and nature of the material from 1½ to 6 cents. All vessels used in connection with the extraction of tannin from the bark must be of copper, heavily galvanized iron, or zinc, as the tannin is quickly precipitated if it comes in contact with iron or steel. Tanners prefer to work with extracts rather than with crude barks, unless they have large plants capable of treating bark in quantity, or unless there is an abundant supply of cheap bark or other source of tannin easily accessible. If the cultivation of wattles is

undertaken on a large scale it will undoubtedly prove most profitable to make tan-bark extracts rather than to ship the much more bulky untreated bark to the market. When dried bark is used for making extract the yield of tannin is usually less than where fresh material is used. When extract is made from the fresh material the solutions contain a large amount of mucilage and gums which are difficult to get rid of.

TANNING PROCESSES.

Hardly any two tanners use exactly the same solutions or methods in the manufacture of leather, but there is a certain resemblance in all processes. Up to 1880 the tanning process was simply to divest the green hide of its hair and adhering flesh and then soak it in vats containing tanning extracts of high concentration. The tanning process under this simple treatment often lasted several years. In 1892 discoveries were made by Fratri Durio of a process by means of which he was able to thoroughly tan hides in a few months instead of as many years. This process, although epoch making in that it created new methods of tanning, was not itself a commercial success; but Durio's discovery gave an impetus to experiments with chemical reagents and the use of the chemical treatment of hides. Improvement in method has been rapid, so that to-day finished leather may be turned out in twenty-five days from the time the hides enter the tannery. The Durio tanning process in brief is as follows: The dried or salted hides are usually soaked for twenty-four hours in warm water. When soft they are placed in a vat with limewater, sharpened with sodium sulphite or soda ash. The liming takes about six days; the hides are then unhaired and worked out and are rinsed in an abundant supply of cold water. The unhairing and fleshing process takes about one day. Fifty or more hides are then put in a slat cage floating in a large vat containing a dilute solution of lactic acid. The cage is agitated occasionally. This is to neutralize the lime in the hide. The deliming process consumes six to eight hours. The hides are then "handled" for nine or ten days, passing through a number of vats filled with 3 to 4 per cent tannin solutions, which have been allowed to ferment until they contain about 1¼ per cent of acetic acid. When taken from the handlers the hides are allowed to drain and then are put in slat drums and half immersed in a 25 per cent tannin liquor. The drums are revolved slowly through the tan vats for from thirty-six to forty hours. The hides are then finished off by being allowed to hang twenty-four hours in a very strong tannin liquor. The sides are then oiled, dried, and rolled for the market. These final operations take four or five days.

The principle of tanning is to soak the hides to make them soft and then remove the flesh, hair, and fat with lime. The immersion of

from eight to ten days in a very weak acid tanning solution soaks the hide so that every fiber becomes swollen and the whole structure of the skin permeable, permitting the more concentrated fixing solutions containing high percentages of tannin to enter into every pore. The object is to swell the skin so that the finished side of leather will be two or three times as thick as it was before being tanned. This swelling of the hide is called "plumping." The final treatment in very strong liquor is intended to weight the hide and fix the fibers which have been thus abnormally swollen. As leather is sold by weight, tanners endeavor to add as much filler as possible without impairing the impermeability and wearing qualities of the leather.

Tanning extracts derived from the wattles and other species of acacias make a very durable quality of leather. Thousands of tons of acacia bark and acacia extracts were imported into Japan during the recent war for the purpose of manufacturing shoes and harness for the army. It is probable that the demand for acacia tan barks will continue and will increase rather than decrease, owing to the superiority of vegetable tannins over purely chemical reagents used for the manufacture of leather. Chrome leathers and other chemically tanned leathers lack durability and will not stand as much wear and tear as hides manufactured into leather by means of organic tannins.

WHAT TO DO WITH THE WOOD.

If the wattle forest is adjacent to a city or a large plantation the wood will find a ready market for domestic purposes. Black wattle wood burns with a clear flame. It is hard and tough, comparable with algeroba in fuel value, but somewhat more difficult to split.

If the forest is not adjacent to a plantation or other market the value of the trees for firewood will be much less. A limited amount can undoubtedly be used for tool handles, axletrees, spokes, etc., but the wood checks in drying so that it will probably find only local use for this purpose.

In this connection it may be well to consider the utilization of the wood in making wood alcohol. Many practical foresters have advocated making forest plantings on a large scale with a view to distilling the product, rather than utilizing it for lumber or other economic purposes, and a claim has been made that large areas of land could be profitably planted to forest trees with this sole end in view.

In the case of the cultivation of the black wattle for its bark alone the wood becomes a by-product, the cost of the production of which may be charged against the cost of the bark.

Assuming that 20 cords of wood can be obtained per acre, at the end of ten years 200 acres of land planted to black wattle would yield 500,000 cubic feet. By distillation 500,000 cubic feet of wood would yield as a minimum 1,650 tons of charcoal, 15,000 gallons of wood

spirit, 380 tons of acetate of lime, and a large amount of wood tar or creosote. Valuing the charcoal at $11 per ton, the wood spirit at 60 cents per gallon, the acetate of lime at $40 per ton, and the creosote at a nominal figure, the total valuation of the distillation products derived from the wood grown on 200 acres would be about $44,000. These figures are taken from actual balance sheets of wood-distillation plants in the United States and Europe.

The one material point of difference between the cost of wood distillation in Hawaii and in other parts of the world would be the difference in the cost of fuel. Counting coal at $3.50 per ton and allowing for interest on investment, depreciation and wear and tear of plant and buildings, the total cost of production should not exceed $20,000, leaving a net profit of about $24,000, or an average of $120 per acre. The weak point in this calculation is the difficulty of finding a market for the charcoal, and also that coal or its equivalent, crude oil, is not at present landed in Hawaii at less than $5.60 per ton, present fuel-delivery contracts having been made when cost of oil and ocean freights were nearly 100 per cent above present rates and prices. If crude oil can be delivered in Hawaii at 90 cents per barrel, it will be an equivalent of coal at $3.60 per ton, approximately the fuel unit of value used in making the above calculations.

The value of wood for distillation purposes has been absolutely neglected in these islands. Thousands of acres of land covered with ohia forests, yielding at the rate of from 30 to 50 cords of timber per acre, have been pulled or cut down and burned simply to get them off the land. Cheap fuel oil can be landed in Hawaii at a cost not greatly above that of coal at the European price of $3.50 per ton. By the utilization of the wood which otherwise might be considered only a waste product, it is believed that the whole expense of plowing, planting, cultivation, harvesting, and marketing of tan bark produced in a wattle plantation will be covered, so that by proper attention to details the total amount of tan bark which the trees are capable of yielding will represent the net profit on the investment.

One thousand acres planted in black wattle should yield $150,000 worth of tan bark at the end of ten years. According to a recent report, there are upward of 4,500 acres of black-wattle plantations in New Zealand and upward of 60,000 acres in Natal. In New Zealand there is no good market for the wood, and no attempt is made to utilize it commercially. In Natal the wood is commercially more valuable than the bark, being largely utilized in timbering mines, a purpose for which its strength and durability make it exceptionally valuable. Some of the New Zealand plantations have reported net profits of $80 per acre from the tan bark alone, placing sales of wood at nominal value over against the interest on the investment and taxes. Some of the South African wattle plantations have yielded

as high as $500 per acre, gross returns, from the sale of tan bark and wood, but in this case the timber value averages 50 cents per tree. In Hawaii a black-wattle forest can be carried through from planting to maturity at an age of 10 years at a cost of from $60 to $80 per acre, figuring the wood as a waste product. With careful management the higher figure should include the cost of harvesting and marketing the crop.

It is an industry which will require large areas of land to insure most economical production, but large acreage will not demand the enormous capitalization usually associated with agricultural operations on a large scale in the Tropics.

INSECT ENEMIES.

The following insects are reported by the entomologist of this station, Mr. D. L. Van Dine, as occurring on the black wattle:

An undescribed species of weevil (*Bruchus* sp.) was taken from seeds purchased in San Francisco. It was presumably introduced into California from Australia or South Africa in the seed.

A leaf hopper (*Siphanta acuta*), known locally as the "torpedo-bug," is abundant.

The fluted scale of California (*Icerya purchasi*) has been noted, but because of the work of its enemy, *Novius cardinalis*, and possibly other predatory insects, it is only periodically in evidence.

A larva of an undescribed moth of the family Tineidæ is very abundant beneath the bark of dead or partly dead trees. The description and name of this insect will undoubtedly appear in the Microlepidoptera part of Fauna Hawaiiensis, which is as yet unpublished.

A long-horned beetle (*Cyelle crinicornis*) is abundant. This is a tropical species of wide geographical distribution, being recorded from Mexico, West Indies, Key West, Texas, etc.

Xystocera globosa is abundant. It occurs also in Japan, Philippines, East Indies, Madagascar, Mauritius, and Java.

Sotenus setiger, not abundant. Probably a native of the islands.

Cresium simplex, not abundant. Wide geographical distribution.

Chalcolepidius erythroloma, not abundant. A native of Chile.

Xyleborus sp., not abundant. Working in branches of felled trees.

Fuller's rose beetle (*Aramigus fulleri*) is quite destructive to the foliage of species of Acacia. For fuller details see Press Bulletin No. 14 of this station.

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HAWAII AGRICULTURAL EXPERIMENT STATION.

J. G. SMITH, Special Agent in Charge.

2.6.08

BULLETIN No. 14.

Marketing Hawaiian Fruits

BY

J. E. HIGGINS,

Horticulturist, Hawaii Agricultural Experiment Station.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. Department of Agriculture.

HONOLULU:
Hawaiian Gazette Co., Ltd.
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

Honolulu, T. H., May 6, 1907.

SIR:—I transmit herewith, and recommend for publication, as Bulletin No. 14, a report on the marketing of Hawaiian fruits, by Mr. J. E. Higgins, the station horticulturist.

Yours truly,

JARED G. SMITH,
Special Agent in Charge.

Dr. A. C. True, Director Office Experiment Stations.

Publication recommended.

A. C. TRUE, *Director.*

Publication authorized.

JAMES WILSON, *Secretary.*

CONTENTS.

ILLUSTRATIONS.

PLATES.

INTRODUCTION.

There are probably no products of the American farm that have passed so rapidly from the realm of luxuries to that of necessities as have fruits. More fruits are being used each year. The great middle class is rapidly becoming a fruit consuming people. Not only has demand for temperate zone fruits increased, but at the same time there has been an enormous development of the semi-tropical and tropical fruit markets. While the people have been learning to regard as necessities the apple, pear and plum, the consumption of bananas has increased and continues to increase at the rate of about one million dollars in value each year. Twenty years ago the banana was an unfamiliar fruit to many in America. Today several of the Pacific Coast markets with their abundant supply of temperate and sub-tropical fruits, consume a car load each of bananas per day. A few years ago the pomelo, or grape fruit, was practically unknown. Today it is everywhere in America and its increasing consumption is surprising even the wholesale dealers.

This development which has been witnessed will certainly be repeated in the case of many tropical fruits now unknown on the mainland of the United States. The pineapple has only begun to gain in popularity. The avocado is a rarity in a few markets and never reaches most of the large cities. The mango is not known. All these and a number of other tropical fruits will certainly make a large place for themselves in the American markets.

Where will these fruits be produced? The eastern markets will be supplied by Porto Rico, Cuba, and the tropical portions of the mainland. There is no place better suited to supply the Western markets than Hawaii. The pineapple business is already assuming large proportions here. With this outlook the Hawaii Experiment Station has undertaken experiments to determine what fruits can be successfully shipped and further to investigate methods of packing and shipment. The experiments also serve to introduce new kinds of fruit in the markets. Experiments have been conducted in a small way for several years, which led to the shipment of several tons of fruit in charge of the Horticulturist of the Station. This shipment was made in August, 1906. The plan and results of the experiments are noted herein.

PINEAPPLES.

EXPERIMENTS IN SHIPPING.

For many years very heavy losses have been experienced in the shipping of pines from Hawaii. Recently these losses have greatly increased and there has been a growing tendency to can the greater part of the crop. Some companies have given up the shipping of the fresh fruits and others have been seriously considering the same step. The Station has undertaken a study of the causes of these losses and has sought remedies.

An experiment was undertaken in shipping the fruits packed according to different methods, treated in various ways, and subjected to the same conditions as other fruits in transit. The stock was purchased from two of the leading growers, part of it coming from the lower or dark colored soils of the Wahiawa region and the remainder from the higher lands which are red in color. The fruit was under the careful supervision of the Station from the time of gathering in the field to unpacking at its destination, with the exception of lot 565-569, the packing of which was supervised by Mr. Byron O. Clark, a well known and very careful grower and packer. The fruits of this lot were gathered on July 29, placed on their crowns in the packing-house and packed July 30. All the other fruits were gathered July 29, packed the same day and on the following morning were shipped to Honolulu. Nearly half of the shipment as indicated in tables I and VI was taken to the U. S. Quarantine Wharf and there subjected to fumigation with formaldehyde gas. On July 31 all crates were placed on board the S. S. Alameda in various decks as also indicated in tables I and VI. The ship sailed on the morning of August 1 and arrived in San Francisco on the afternoon of August 7. The fruit was immediately removed from the ship, taken to the ferry and shipped by rail to Portland, Oregon. As this route leads through the Sacramento Valley and the weather was exceedingly warm, the test for the fruit was a most severe one. The shipment arrived in Portland August 9 and an examination was begun at once.

The Causes of Loss.

It is not to be supposed that any single cause is wholly responsible for the heavy losses which the pineapple shippers have experienced, but rather there are a combination of causes, some of which must be removed by the growers and shippers, and some by the steamship companies if the highest success in shipping is to be attained. In June, 1906, the writer visited the plantations at Wahiawa to determine if possible some of these causes. It was discovered that pineapples were decaying while still green and unfit for use, the probable cause being the presence of a parasitic fungus. Specimens were submitted to Dr. N. A. Cobb who made a study of them and found them infested with a fungus which is common upon cane in these Islands and which gives rise to the disease known as the "Pineapple disease" of sugar-cane.[1] This fungus, *Thielaviopsis ethaceticus* Went, was afterward repeatedly found upon fermenting pines. (Plate I.) It should be said in passing, that this disease appears to have received its name not from having been first discovered on pines but from the fact of its producing in cane an odor of decaying pineapples.

Since this is in all probability a very potent cause of loss in the shipping of fresh pineapples, it was determined that methods should be sought to bring early relief to the shippers by devising methods to prevent the progress of the disease in the fruit while in transit. Other methods should be sought to stay the progress of the trouble in the field, but methods for treatment of the fruit to destroy the fungus spores have demanded first consideration. The use of a 3 per cent. solution of commercial formalin (=40 per cent. formaldehyde) as a medium in which various kinds of fruits might be dipped to delay decay has been suggested and tried at least in laboratory experiments at Kew[1] and is reported to have been quite successful in the case of some fruits. Preliminary experiments with this solution for pineapples were tried at the Hawaii Station but the results were not satisfactory. This treatment resulted in a shrinkage of the segments of the fruit or the "eyes" as they are commonly called, which deformed the fruit more or less. It was conceived that fumigation with formal-

[1] J. G. Smith, Press Bulletin, No. 9, Hawaii Experiment Station.

[1] Journ. Bd. Agr. (London), 12 (1905) No. 5, p. 305.

Plate I.—Pineapple destroyed by Thielaviopsis ethaceticus Went.
Photo. by Dr. N. A. Cobb.

dehyde gas might be equally or more effective and could be applied much more economically. Some preliminary experiments with this method of treatment were carried on through the coöperation of the U. S. Public Health and Marine Hospital Service, since there was no equipment at the station for carrying on this work. These experiments though on a very small scale, resulted in considerably prolonging the life of the fruit and led to further experiments on a much larger scale.

With this fungus as a probable cause of severe losses, any practices which would tend to spread the spores or make inviting points of entrance for the same on the fruits would greatly increase the difficulty. It is customary with some of the shippers to pull off the bracts which subtend the fruits, in preparing them for shipment. This produces slight abrasions at the base of the pineapple which make a means of entrance into the fruit for the fungus spores. Experiments were therefore tried to determine whether this really occurs. A number of packages of fruit marked 500 to 509 as indicated in table I were prepared by cutting the bracts at a considerable distance from the fruit instead of pulling them off. Otherwise the packing and treatment was the same as that given to lot 545 to 554.

A large proportion of the decay and fermentation appears to have its origin at the base of the fruit (Plate I) and may result from the spores having found entrance through the stem where it has been cut. These cut surfaces often keep moist for many days and in some cases never become dry. The stems which are cut long appear to dry more readily than those cut short. Fifteen small crates of fruit were gathered and packed with their stems cut 2½ to 3 inches from the fruit. These are marked 510 to 524 in table I. Otherwise they received the same treatment as lot 545 to 554. The length of stem in ordinary practice is about 1¼ inches. It has been suggested that fruits be placed on their crowns and allowed to cure for a day or two before packing. This matter also was tested by allowing those designated lots 565 to 569 in table I, to remain as indicated in the packing-house for about 24 hours. If other lots could have been left two and three days respectively a better test of the advantages of this method might have been made. Otherwise the treatment and packing were the same as lot 545 to 554, used as a standard of comparison.

The use of paper as wrapping material for fruit of all kinds has become very common, in fact is of almost universal application. Pineapples are shipped from Florida with a wrapping of heavy paper, although this practice has not as yet been followed in Hawaii. There are several advantages which may be claimed for it. It tends to prevent a free distribution of the spores of any fungus from fruit to fruit and prevents slight moisture from one fruit getting to the adjacent one. In the case of pineapples, a further advantage is in the much brighter and more attractive color attained by wrapped fruit. Certain packages therefore were wrapped in paper, being closed at the base and pressed as close as possible to the crown. Since the fumigating could not be done at the plantation, certain other packages, marked 535 to 544 in table I, were wrapped in paper, but the ends were left open that there might be thus a freer access of the fumes of formaldehyde in treatment. Otherwise both of these lots were as lot 545 to 554.

The relative merits of hay and excelsior as a packing material have been somewhat in dispute. The packages indicated in table I were packed with hay which is gathered in the neighborhood of the plantations and which is commonly used in packing. The same number of crates was packed in an exactly similar manner except that excelsior was used instead of hay. These are marked 545 to 554 in table I and represent in other respects also the methods in common use at the plantation where the fruit was obtained, and may therefore be taken as a check or standard of comparison for the other methods of packing and treatment. Hay is the packing material in general use in shipping Hawaiian pineapples.

Since a considerable part of the losses of the past appear to have been due to the shipping facilities, a test was made of the different decks of the ship to determine where the fruit carries best. In this work we had the careful coöperation of the Oceanic Steamship Company and the captain and officers of the steamship Alameda. Fruits were stored on the main deck, in the 'tween decks and in the orlop deck as indicated below. (Tables I and IV).

The detailed results of the examination of the fruit from the lower fields are indicated in table I.

TABLE I. *Detailed results with fruit from lower fields.*

No. on Package	Style of Package[1]	MANNER OF PACKING, ETC.	Fumigated[2]	Location in Ship[3]	Results on Examination in Portland: Green, Sound	Green, Unsound	Ripe, Sound	Ripe, Unsound
500	8/30	Bracts cut, not pulled	F.	T. D.	3	....	5	....
501	"	" " " "	"	M. D.	3	....	5	....
502	"	" " " "	"	"	3	......	5	....
503	"	" " " "	"	"	3	....	5	....
504	"	" " " "	"	"	2	....	5	1
505	"	" " " "	N.	T. D.	1	....	6	1
506	"	" " " "	"	M. D.	....	....	7	1
507	"	" " " "	"	"	5	....	1	2
508	"	" " " "	"	"	1	....	7	....
509	"	" " " "	"	"	1	....	7	....
510	6/30	Long stems	F.	T. D.	....	....	4	2
511	"	" "	"	M. D.	1	....	4	1
512	"	" "	"	"	....	....	6	....
513	"	" "	"	"	2	....	4	....
514	"	" "	"	"	2	1	2	1
515	"	" "	"	"	1	....	5	....
516	"	" "	"	"	....	....	6	....
517	"	" "	"	"	1	....	5	1
518	"	" "	N.	T. D.	1	....	2	3
519	"	" "	"	M. D.	2	....	2	2
520	6/25	" "	"	"	3	....	3	....
521	"	" "	"	"	1	....	4	1
522	"	" "	"	"	1	....	4	1
523	"	" "	"	"	2	....	4	....
524	"	" "	"	"	4	....	2	....
525	"	In paper, ends closed	F.	T. D.	....	....	2	4
526	"	" " " "	"	M. D.	1	....	4	1
527	"	" " " "	"	"	....	....	4	2
528	"	" " " "	"	"	1	....	5	....
529	"	" " " "	"	"	....	....	5	1
530	"	" " " "	N.	T. D.	....	....	4	2
531	"	" " " "	"	M. D.	....	....	4	2
532	"	" " " "	"	"	1	....	2	3
533	"	" " " "	"	"	....	....	5	1
534	"	" " " "	"	"	1	....	3	2
535	"	In paper, ends open	F.	T. D.	....	....	4	2
536	"	" " " "	"	M. D.	....	....	4	2
537	"	" " " "	"	"	....	....	6	....
538	"	" " " "	"	"	....	....	5	1
539	"	" " " "	"	M. D.	1	....	5	....
540	"	" " " "	N.	T. D.	1	....	3	2
541	"	" " " "	"	M. D.	....	....	5	1
542	"	" " " "	"	"	1	....	4	1
543	"	" " " "	"	"	3	1	....	2
544	"	" " " "	"	"	....	1	3	2

[1] The first number in the expression "8/30" represents the number of fruits in the crate; the second figure, the approximate weight of the fruit. Thus 8/30, indicates that there are eight fruits whose combined weight approximates 30 pounds. The individual fruits therefore weighed a little less than 4 lbs.

[2] Those marked "F" received the formaldehyde fumigation. Those marked "N" did not.

[3] T. D. 'tween decks. M. D. main deck.

TABLE I—*Continued.*

No. on Package	Style of Package[1]	MANNER OF PACKING, ETC.	Fumigated[2]	Location in Ship[3]	RESULTS ON EXAMINATION IN PORTLAND			
					GREEN		RIPE	
					Sound	Unsound	Sound	Unsound
545	6/25	As usual, with excelsior	F.	T. D.	....	....	4	2
546	"	" " " "	"	M. D.	....	....	1	5
547	"	" " " "	"	"	1	....	3	2
548	"	" " " "	"	"	3	....	2	1
549	"	" " " "	"	"	1	....	2	3
550	"	" " " "	N.	T. D.	....	....	2	4
551	"	" " " "	"	M. D.	2	....	4	....
552	"	" " " "	"	"	1	....	2	3
553	"	" " " "	"	"	....	....	3	3
554	"	" " " "	"	"	1	....	3	2
555	"	" " " hay	F.	T. D.	....	....	5	3
556	"	" " " "	"	M. D.	....	....	7	1
557	"	" " " "	"	"	1	....	6	1
558	"	" " " "	"	"	1	....	5	2
559	"	" " " "	"	"	1	....	3	2
560	"	" " " "	N.	T. D.	1	....	1	6
561	"	" " " "	"	M. D.	6	....	2	....
562	"	" " " "	"	"	....	....	4	4
563	"	" " " "	"	"	3	....	5	....
564	"	" " " "	"	"	1	....	4	3
565	"	Excelsior, cured one day	"	T. D.	1	....	5	2
566	"	" " " "	"	"	2	....	2	4
567	"	" " " "	"	M. D.	2	....	2	4
568	"	" " " "	"	"	....	....	4	4
569	"	" " " "	"	"	1	....	4	3

These results have been brought together in more concise form in the following table:

TABLE II. *Summary of results with fruits from lower fields.*

Lot No.	MANNER OF HANDLING AND PNCKING	Fumigated	Sound	Unsound	Total	Loss, %	Difference in favor of Fumigation, %	Loss Reduced, %
500 to 504	Bracts cut, not pulled	F.[1]	39	1	40	2.5	7.5	75.
505 to 509	" " " "	N.[2]	36	4	40	10.	....	....
510 to 517	Long stems	F.	43	6	49	12.2	4.4	26.6
518 to 524	" "	N.	35	7	42	16.6	....	....
525 to 529	In paper, ends closed	F.	22	8	30	26.6	6.7	20.2
530 to 534	" " " "	N.	20	10	30	33.3	....	....
535 to 539	In paper, ends open	F.	25	5	30	16.6	16.7	50.2
540 to 544	" " " "	N.	20	10	30	33.3	....	....
545 to 549	As usual, with excelsior	F.	17	13	30	43.3	....	....
550 to 554	" " " "	N.	18	12	30	40.	-3.3	-8.2
555 to 559	As usual, with hay	F.	29	9	38	23.1	9.4	29.
560 to 564	" " " "	N.	27	13	40	32.5	....	....
	Totals for fumigated stock	....	175	42	217	19.3	7.1	26.9
	" " unfumigated stock	....	156	56	212	26.4	....	....
565 to 569	Cured one day	....	23	17	40	42.5	....	....

[1] F.=fumigated stock.

[2] N.= stock not fumigated.

Segregating the fumigated and unfumigated stock for purposes of comparing the relative advantages of the different types of packing and previous treatment, and placing first the lot which may be regarded as exemplifying the methods which have been pursued in common practice, we have the following table:

TABLE III. *Comparison of methods of packing.*

STYLE OF PACKING	FUMIGATED Loss %	FUMIGATED Loss Reduced %	UNFUMIGATED Loss %	UNFUMIGATED Loss Reduced %
As usual, in excelsior	43.3	....	40.	...
" " " hay	23.1	46.7	32.5	18.8
" " but bracts cut	2.5	94.3	10.	75
" " " long stems	12.2	71.9	16.6	58.5
" " in paper with ends closed	26.6	38.6	33.3	16.8
" " " " " " open	16.6	64.	33.3	16.8
" " cured one day	....	....	42.5	—6 2

COMPARISON OF RESULTS.

It must be noted in the above table that the results recorded in the second, third and following lots are not comparable with each other, but only with the first lot. Each lot was packed like the first lot except in the one particular indicated. Therefore all comparisons are made with the first or check lot.

Excelsior versus hay as a medium for packing. The experiments show quite unexpected results in respect to the relative value of hay and excelsior for packing material. It will be noticed by reference to table III that both the fumigated and unfumigated stock carried much better in hay than in excelsior. In the case of the fumigated lots as high as 46.7 per cent. of the loss in excelsior was saved in the fruit packed in hay and in the unfumigated lots 18.8 per cent. Why this should be is not clear. Excelsior is clean and might be expected to be as free from infection as any packing material which could be procured. It has been used in the packing of apples in the East for trans-Atlantic shipment and no evil results have been reported. It is possible that the much larger quantity which is used may be the cause of the apparent advantages of hay. The hay being much cheaper the packers use it very freely, filling all spaces between the fruits. In using excelsior the packing is not so tight but it is not at all impossible that the excelsior is in itself injurious as the above results would appear to indicate. The results of the experiment, however, are suf-

ficiently marked to suggest the importance of further experiments in the use of these two packing materials.

Cutting the Bracts. The results here are most pronounced. It will be noticed that in the fumigated stock, the very heavy loss of 43.3 per cent. in the check lot was reduced to 2.5 per cent. in the lot which had exactly the same packing and treatment in every respect except in the matter of the removal of the bracts subtending the fruits. This represents a difference of 94.3 per cent. of the total loss of the standard check lot. In the unfumigated stock the loss was 10 per cent., this being, 75 per cent. less than that of the check. In both fumigated and unfumigated stock therefore the results are very marked against the practice of pulling off the bracts.

Long Stems. Here there appears to have been a marked difference in favor of the fruits which were cut with long stems. This appears perfectly reasonable and might be expected since the moist surface near the base of the fruit, when the stem is cut short, would furnish a most inviting medium for the propagation of the fungus which destroys the pineapple. It will be claimed by the packers that long stems are inconvenient in packing and that a much larger crate would be required, nevertheless the primary aim must not be convenience in packing, or even economy of space, but rather to get the fruit to the market in good condition. Hence if future results should be at all commensurate with those of the present experiments the saving would abundantly justify very great increase in the cost of packing. As a matter of fact, however, the size of the crate need not be greatly increased, not more than two or three inches being added to one dimension.

Wrapping in Paper. The fruits wrapped in paper with the ends closed and those with the ends open, carried with identically the same percentage of loss in the case of unfumigated stock, namely 33 1-3 per cent. In this there was a reduction in the loss from that of the check lot of 16.8 per cent., due apparently to the use of wrapping. Referring to the fumigated stock it will be observed that the loss was much greater in the case of the fruits wrapped with paper with the ends closed than with those having the ends open. Though the fumes of formalin are exceedingly penetrating it is reasonable to suppose that there would be freer access to the fruit when the ends of the wrapping are left open and particularly so when the fumigation is continued for only a short time. The results therefore indicate that if fruits are to be wrapped, it should be

after the fumigating process is completed. In the case of both fumigated and unfumigated stock the figures indicated a very appreciable advantage in favor of wrapped fruit. Another advantage which is not indicated in the figures, lies in the very much better color attained by the wrapped fruit. The paper used should be quite heavy; a light thin paper breaks too easily. The Florida packers use a glazed paper rather than one of rough finish.[1] Wrapping also protects the fruit from infection with spores from other pineapples or which may be lingering about the decks of the ship.

Curing the Fruit. The cured fruits which remained twenty-four hours in the packing-house previous to packing, appear to have shown a very slight disadvantage in this method of packing. So far as the fungus is the cause of the losses it is to be supposed that the drying of the stems would lessen the opportunities for the progress of the disease. If however the drying or curing process proceeds in the packing-house which has not been fumigated, it may offer the best possible opportunity for infection from the spores which would be numerous in an unfumigated packing room. While this experiment can be regarded in no sense as conclusive proof of the disadvantage of curing, it is certainly safe to say in view of our present knowledge of the cause of decay that if curing is to result in any gain it must be carried on in a scrupulously clean packing room or in the open sunlight. It would be interesting and profitable to carry this experiment further by allowing separate lots to remain two or three days respectively. Such tests should be carried on in connection with the experiments in fumigation.

RESULTS OF FUMIGATION.

Referring now to table II it will be observed that approximately half of each lot packed in a given manner was subjected to the process of fumigation with formaldehyde; therefore lot 500 to 504 is comparable with lot 505 to 509; lot 510 to 517 with lot 518 to 524 and so on. In every instance except lots 545 to 554, it will be noticed that there has been a very considerable reduction in the loss in the case of fumigated fruit, varying from 20.2 per cent. to 75 per cent. in the different lots. Comparing lot 545 to 549 with lot 550 to 554, the results are practically negative and may be regarded as one of the exceptions which almost always occur in a series of tests.

[1] H. H. Hume, Florida Agricultural Experiment Station, Bulletin No. 84.

With a very pronounced advantage in favor of fumigation in the case of all the other lots the evidence is very strong that the progress of the development of the fungus was arrested by this process. The large saving in the loss cannot be regarded as incidental. The evidence is the more strong because of at least two unavoidable factors which would tend to minimize the results. First the fumigation was not performed until after the fruits had been gathered 24 to 30 hours, thus affording spores of the fungus an opportunity to germinate and send mycelia[1] into the tissue of the fruit before treatment.

FRUITS FROM THE UPPER OR RED SOILS.

The fruits from the upper or red soils were gathered the same day and under conditions similar to those under which the pines from the lower fields were gathered. The details of packing, treatment, location in ship and the results of examination are indicated in the following table:

TABLE IV. *Detailed results with fruits from upper or red soils.*

No. of Package	Date of Packing	MANNER OF PACKING	Fumigation	Location	GREEN		RIPE	
					Sound	Unsound	Sound	Unsound
650	7/29/06	Grass in bottom only. Paper on each fruit. Headed under pressure	N.	O. D.[2]	..	..	38	2
651	"	Grass in bottom only. Paper on each fruit. Headed under pressure	F.	O. D.	2	...	35	2
652	"	As usual. *Much grass* around each fruit	N.	O. D.	1	..	28	1
653	"	As usual. *Much grass* around each fruit	F.	O. D.	1	..	28	1
654	"	In grass	N.	M. D.[3]	..	..	5	1
655	"	" "	"	"	1	..	4	1
656	"	" "	"	"	..	..	5	1
657	"	" "	F.	"	4	..	2	..
658	"	" "	"	"	4	..	1	1
659	"	" "	"	"	..	..	5	1

[1] The vegetative part of the fungus.

[2] Orlop Deck. [3] Main Deck.

The details of the above are brought together in more concise form for study in the following table:

TABLE V. *Summary of results with fruits from upper or red soils.*

Lot No.	MANNER OF PACKING, ETC.	Location in Ship	Fumigation	Sound	Unsound	Total	Percentage of Loss.	Difference in Favor of Fumigation	Loss Reduced, %
651	Large crate. Fruits wrapped in paper, hay in bottom only. Headed tight against fruit	O. D.[1]	F.[2]	37	2	39	5.1	....	....
650	Large crate. Fruits wrapped in paper, hay in bottom only. Headed tight against fruit	"	N.[3]	38	2	40	5.	—.1	....
653	No paper. Much hay. Each fruit wrapped in hay	O. D.	F.	29	1	30	3.3	....	....
652	No paper. Much hay. Each fruit wrapped in hay	"	N.	29	1	30	3.3	....	....
657 to 659	Small crates. In hay in usual manner	M. D.	F.	16	2	18	11.1	5.5	33.2
654 to 656	Small crates. In hay in usual manner	"	N.	15	3	18	16.6	....	....

[1] Orlop deck.
[2] Fumigated.
[3] Not fumigated.

COMPARISON OF RESULTS.

Formaldehyde Fumigation. Comparing 650 with 651; 652 with 653 and so on, it will be observed that in the first two instances the results of the formaldehyde treatment were practically negative. The loss, however, was extremely light both on treated and untreated fruit for reasons to which there will be occasion to refer below. Comparing lots 654 to 656 with lots 657 to 659, a marked diminution in the loss is observable in the case of the fumigated lots, confirming the results as found on the pineapples from the lower or dark colored soils.

Dark soils vs. red soils. A just comparison of the fruits from the two kinds of soils can be made only between lots 657 to 659, (Table V) and lots 555 to 559 (Table II) all of which were fumigated; and further between lots 654 to 656 (Table V) and lots 560 to 564 (Table II) which were not fumigated. In the first instance the fumigated fruit from the red soils shows a loss of 11.1 per cent. while that from the dark soils is 23.1 per cent. The unfumigated fruit from the red soil shows 16.6 per cent. loss in contrast with 32.5 per cent. on the fruit from the lower tract or dark soils. While the extent of the experiments is entirely too limited to justify any conclusions the results suggest that the fruits from the lower fields may be more subject to decay than those from the upper fields. If such is the case, it is probably due to a greater prevalence of the fungus *Thielaviopsis ethaceticus* Went, at least on the fields from which the fruits for these experiments were taken. The dark soils are unusually high in manganese, which may or may not be a contributing cause.

Grass as a packing material vs. paper wrapping only. The fruits wrapped in hay, which was also packed tightly in the intervening spaces, carried with slightly less loss than those wrapped in paper only, the difference being about 1.7 per cent. of the whole. Against this, must be reckoned the additional expense for crates and the extra freight charges for the more bulky method of packing. The crates carry approximately 30 five-pound pines or 150 lbs. of fruit if the hay is used. The hay being omitted, about ten more fruits can be placed in the same crate or about 50 lbs. additional. This means that to carry a given weight of pineapples packed with hay in the usual manner, will require one-third more crates than would be necessary were the hay eliminated except a thin layer in the bottom and at the top. This increase of 33 1-3 per cent. in the

bills for crates, involves also an increase of 33 1-3 per cent. in freights since these charges are calculated per ton measurement. Roughly, it may be said that it costs about $6. more per ton (weight) to ship pineapples in hay, than it would without it. The cost of the paper could not greatly exceed that of the hay since the total cost per crate for paper need not be greater than 10 cents. The Florida packers pay from $1.00 to $1.45 per 1000 sheets according to quality, which would be less than 6 cents for the paper for 40 fruits. The sheets for Hawaiian pines, however, would require to be larger.

Clearly, the free use of hay involves large expense. Can it be eliminated? The indications of the present experiments are that it can and with financial gain to the packers. If the results of these limited trials shall be confirmed by future experiments, very little hay should be used in packing. This would add much also to the attractiveness of the package.

The size of crate. It is not to be expected, however, that 200 lbs. of pineapples can be a desirable size of package. Even 150 lbs. is too great. The other crate which has been used extensively by at least one company and which carried the greater portion of fruit in these experiments will contain from 30 lbs. to 40 lbs. It holds from six to eight fruits in a single layer.

None of these crates appear to exactly fulfill the requirements. The amount of fruit in the small crate is desirable and the package is neat and attractive in appearance. The objection lies in the difficulty experienced in making a tight pack. There being but one layer of fruit it must be of uniform diameter to fit the crate. The problem of crates for pineapples is yet unsolved and some medium ground between these two extremes must be sought or a more careful grading of the fruit must be made for the single layer package. Possibly a crimped or corrugated straw-board such as was used in the papaia shipping experiments (see p. 34) could be successfully used with pineapples for fancy packages.

MERITS OF DIFFERENT PARTS OF SHIP.

By reference to table I, it will be observed that one fumigated and one unfumigated package from each lot were located in the "'tween" decks of the ship as indicated by the letters "T. D." All the other crates containing pineapples from the lower or dark lands were placed on the main deck as indicated by the letters "M. D." The results are brought together in the following table:

TABLE VI. *Results on different decks.*

FUMIGATED STOCK

Lot	'Tween Decks: Sound	Unsound	Total	Loss, per cent.	Main Deck: Sound	Unsound	Total	Loss, per cent.	Reduction in Loss, per cent.
500 to 504	8	....	8	....	31	1	32	....	....
510 to 517	4	2	6	....	39	4	43	....	....
525 to 529	2	4	6	....	20	4	24	....	....
535 to 539	4	2	6	....	21	3	24	....	....
545 to 549	4	2	6	....	13	11	24	....	....
555 to 559	5	3	8	....	24	6	30	....	....
Totals	27	13	40	32.5	148	29	177	16.3	53.

STOCK NOT FUMIGATED

Lot	'Tween Decks: Sound	Unsound	Total	Loss, per cent.	Main Deck: Sound	Unsound	Total	Loss, per cent.	Reduction in Loss, per cent.
505 to 509	7	1	8	....	29	3	32	....	....
518 to 524	3	3	6	....	32	4	36	....	....
530 to 534	4	2	6	....	16	8	24	....	....
540 to 544	4	2	6	....	16	8	24	....	....
550 to 554	2	4	6	....	16	8	24	....	....
560 to 564	2	6	8	....	25	7	32	....	....
565 to 569	10	6	16	....	13	11	24	....	....
Totals	32	24	56	42.8	147	49	196	25.	41 6

By reference to the above table it will be seen that even in the case of the fumigated stock the loss was extremely heavy in the "'Tween decks," *amounting to 32.5 per cent.* On the Main deck the loss falls to 16.3 per cent. representing a reduction in the loss of 53 per cent. In the case of the unfumigated stock in the 'tween decks, the loss runs up to the alarming proportions of 42.8 per cent. The same kind of fruit with exactly the

same treatment in other respects when placed on the main deck, shows a loss of 25 per cent. This, it will be noted, is a reduction in the loss, of 41.6 per cent. due apparently to better conditions on ship-board. The improved conditions on ship-board together with fumigation brought down the loss to 16.3 per cent. Even a loss of 16.3 per cent., however, is too great and can be avoided.

Referring now to table IV, it will be observed that crates Nos. 650, 651, 652 and 653, were located in the orlop deck while crates Nos. 654 to 659 were placed on the main deck with the fruits from the lower or dark soils. Segregating the results on these two decks we have the following table:

TABLE VII. *Results on main and orlop decks.*

FUMIGATED										NOT FUMIGATED									
ORLOP DECK					MAIN DECK					ORLOP DECK					MAIN DECK				
Lot No.	Sound	Unsound	Total	Loss, per cent.	Lot No.	Sound	Unsound	Total	Loss, per cent.	Lot No.	Sound	Unsound	Total	Loss, per cent.	Lot No.	Sound	Unsound	Total	Loss, per cent.
651	37	2	39	5.1	657 to 659	16	2	18	11.1	650	38	2	40	5.	654 to 656	15	3	18	16 6
653	29	1	30	3.3	......	......	......	......	......	652	29	1	30	3.3	......	......	......	......	......
Totals	66	3	69	4.3	Totals	......	......	......	11.1	Totals	67	3	70	4.2	Totals	......	......	......	16.6

There is a striking contrast in the above figures, showing a loss of 11.1 per cent. on the main deck and only 4.3 per cent. on the orlop deck with fumigated fruit; and with fruit not fumigated 16.6 per cent. on the main deck in comparison with 4.2 per cent. on the orlop deck. Recalling again the heavy losses in the 'tween decks the question naturally arises what were the conditions prevailing in each of these parts of the ship. The proper conditions on shipboard for the successful shipping of fruit may be enumerated as follows:

1. Ventilation,
2. Dryness,
3. Reasonably low temperatures,
4. Careful handling and steeving.

The conditions were far better on the main deck than in the 'tween decks because of better ventilation and lower temperatures. On account of the calmness of this voyage, the freight port of the main deck could be kept open continuously, affording free circulation of air. The ports of the 'tween decks were of course closed tightly. The temperatures here read as follows: Aug. 2, 82° F.; Aug. 3, 79° F.; Aug. 4, 75° F.; Aug. 5, 75° F.; Aug. 6, 73° F.; Aug. 7, 76° F.

Although these temperatures are not excessively high for the first day or two considering that of the atmosphere, they would have fallen much lower on August 5, 6 and 7, had there been free access for the outside air. The heat in itself, however, though hostile to the keeping of the fruit, is less so than stagnation of warm air. The latter condition with moisture furnishes ideal environment for the growth of fungi which destroy fruit. In 'tween decks, only one of the desirable factors prevailed. It was dry. But it was hot and unventilated. The main deck was cool, well ventilated, but so damp, that the packing material became wet. The orlop deck furnished the best conditions, being fairly dry, cool, and well ventilated by means of a wind-sail. If these conditions could always be maintained in the orlop deck, as they were on this voyage, it would be the most desirable part of the ship which was tested. But unfortunately, this can be done only when the weather is favorable. In case of rain or heavy seas the wind-sail must be taken down and the hatches closed. The temperatures rise, the air becomes stagnant and the orlop deck proves no better than the 'tween decks. Under these weather conditions, the freight ports of the main deck also must be closed and no part

of the ship furnishes suitable conditions for successful shipment of fruit.

Furnishing the requisite conditions. Furnishing mechanically forced draft through all parts of the ship where fruit is carried, is the only possible means of equipping a steamship for this tropical fruit trade so that she can safely carry her cargo. This applies equally to bananas, pineapples or any fruit not carried in the refrigerated compartments. It is gratifying to know that at least one line of boats carrying Hawaiian fruit, is considering the matter of installing mechanically forced draft. The extent of the fruit carrying trade in the near future, will depend in large degree upon the shipping facilities offered.

THE PROCESS OF FORMALDEHYDE FUMIGATION.

The apparatus and material used in formaldehyde fumigation are neither expensive nor difficult to manage. The apparatus ordinarily used consists merely of a small boiler or cylinder into which the materials are poured, and a lamp or stove which burns kerosene under pressure to supply the heat which aids in liberating the formaldehyde gas from its solution. The materials are simply formalin (40 per cent. formaldehyde) and calcium chloride (Ca Cl.) in the proportion of ten gallons of the former to twenty pounds of the latter as the stock solution. The quantity of this stock solution which should be used in fumigating pineapples is as yet wholly undetermined. In the experiments recorded in this bulletin, four quarts of the stock solution were used in a room 18x19x20 feet. The time of exposure was about an hour and a half, after which time the doors and windows were thrown open and the gas allowed to pass out. Further experiments must be carried on to determine more definitely the quantity of the stock solution and the time of exposure which is best adapted for the purpose.

Commercial formalin costs about $1.50 to $2.00 per gallon. Calcium chloride can be purchased for about 20 cents per pound in quantity.

Fumigate immediately after gathering the fruit. It will be noticed that the fumigating in the above experiments was unavoidably delayed until a day or two after the fruit was gathered. This, however, cannot be recommended. It should be performed as soon as possible after the fruit is gathered in order to destroy the spores of the fungus before they have

germinated and the vegetative organs have penetrated the tissue of the stem or of the fruit.

The room for use in fumigating should be fairly tight and should be constructed of wood. It should not have an iron roof or ceiling which would come in contact with the fumes since the latter destroy iron.

A PROPOSED NEW METHOD OF FORMALDEHYDE FUMIGATION.

The use of formaldehyde as a disinfectant has become increasingly common and several attempts have been made to develop a method of liberating the gas from its aqueous solution without the use of apparatus especially constructed for the purpose. The State Board of Health of Maine report the use of the following method with great success and efficiency.[1]

The rule for ordinary disinfection given by the State Board of Health of Maine is as follows:

For each 1000 cubic feet of room space to be disinfected, use 7½ ounces of the permanganate to one pint of formaline.

The time of exposure which is recommended is four hours. Probably a shorter time would suffice for fruits since the dosage and the time have been worked out for disinfection against infectious diseases where a very large margin of safety must be allowed. This method of liberating formaldehyde is now being used in fumigation experiments by the Hawaii Experiment Station.

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[1] Bulletin, State Board of Health of Maine, Vol. 1, No. 7.

"In carrying out this process of disinfection the requisites are simply the ordinary so-called 40 per cent. formaldehyde solution, commercial permanganate of potassium, and a vessel to mix them in.

"The required quantity of permanganate for each pint of formaldehyde is 7½ ounces. The permanganate is first put into the dish and the formaldehyde is then poured upon it. The permanganate must *go in first*. Before the mixture is made everything must be in readiness, because a rapid flight from the room must be made. Leave the room closed up tightly four hours.

"The vessel in which the permanganate and formaldehyde are to be mixed should be of considerable size, else the vigorous foaming will throw a part of the mixture upon the floor. A flaring ten-quart tin pail is a suitable and large enough vessel unless more than three pints of formaldehyde are to be used, and even then until the disinfector is well acquainted with this process, it would be a safe precaution to set the pail inside of a large pan. In this, as in all methods of chemical disinfection, the disinfectant action is more efficient the warmer the room."

"It is necessary to adjust carefully the relative quantities of permanganate and formaldehyde ——————"

MARKET CONDITIONS.

The study of the markets from Fresno, California, to Vancouver, British Columbia, reveals the unmistakable fact that there is an exceedingly inefficient distribution of pineapples. It was found that even some employees of wholesale fruit houses were quite unacquainted with the pineapple and unfamiliar with the methods of using it for food. In one case it was asked whether it was necessary to cook pineapples before eating them. There is no permanent and reliable supply of pineapples in the large markets throughout Oregon, Washington and British Columbia during the season. The fruits come in spasmodically and the consumer or even the retail dealer never knows when they are available. This is true, only to a less degree in California. These markets are supplied with fruit in this indifferent and uncertain way from Florida and Hawaii. The fruits from Florida come by rail and are packed in crates of smaller size than the standard large sized Hawaiian crate. The pineapples are much smaller than the Hawaiian fruit and are less juicy and therefore less subject to decay. They range in size from 2½ to 4 pounds. The Hawaiian fruit ranges from 4 to 9 pounds, has abundant juice and appears to be more subject to decay. The Florida fruits have been in the market for a long time and the consumers have become accustomed to buying them by the piece or by the dozen, at prices which would be quite low for the much larger sized Hawaiian fruit.

The market demands a fruit of medium size which can be retailed at from thirty to forty cents each. The fruits ranging from 6 to 9 pounds can be sold only in very limited quantities since they must be retailed at from forty to sixty cents and are larger than the average family can consume. There is also a heavier loss in the shipping of these extremely large fruits. The quantity which any of these markets can handle with safety, is determined very largely by the price. It is a well known principle in the handling of all kinds of fruit, that the sales increase in indirect ratio with the price; as the price lowers, the sales become rapid and large quantities of fruit are moved in a very short time. In seeking to build up a market it will be well not to hold the fruit at too high a figure.

THE AVOCADO.

The avocado or "alligator pear" has been shipped to a limited extent. Most shipments which have been made have arrived in such bad condition that little encouragement has been offered to the development of a trans-Pacific trade in these fruits. Honolulu prices have also ruled high. Experiments conducted by this Station in the storing of avocados in refrigeration, led to the belief that with proper handling and care, this fruit should be shipped successfully. Hence, experiments were undertaken as a part of the plan for the shipping of tropical fruits.

The fruit was packed from July 28 to July 31, 1906, was taken on board the steamship Alameda on the afternoon of July 31 and placed in the refrigeration compartment. A few packages were put on the main deck where ventilation was good. The fruits that were picked previous to July 31, were placed in cold storage the day on which they were picked and remained there until the afternoon of July 31.

The steamship Alameda sailed, as stated above, August 1 and arrived in San Francisco, August 7. The fruit was immediately transferred to the railway and carried by express to Portland, Oregon, arriving August 9. It will thus be seen that the fruit was subjected to unusually trying conditions, being taken from cold storage and shipped by ordinary express for nearly two days through a hot section of country. These conditions were more severe than would be considered for any commercial venture in fruit shipping, which fact makes the outcome the more encouraging to those interested in the development of the industry. The results of these experiments indicate that it is possible to ship this fruit to direct markets without greater loss than is experienced in average fruit shipments. The chief points of importance to be considered in shipping avocados, as learned from these experiments and from the principles which have been demonstrated in all fruit shipments, may be summed up in the following paragraphs:

HOW TO SHIP AVOCADOS.

Picking. The first step is the proper picking of the fruit. Here is where a great many mistakes have been made. Fruit of any kind carelessly picked cannot be expected to reach its destination in a sound condition. The slightest bruising will certainly show its effects when the fruit becomes ripened.

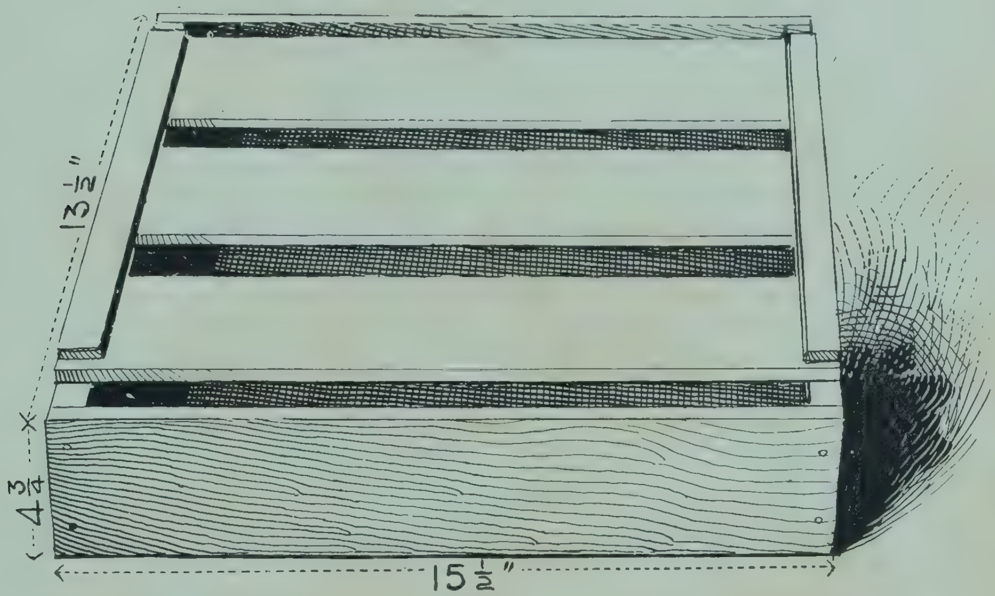

Fig. 1.

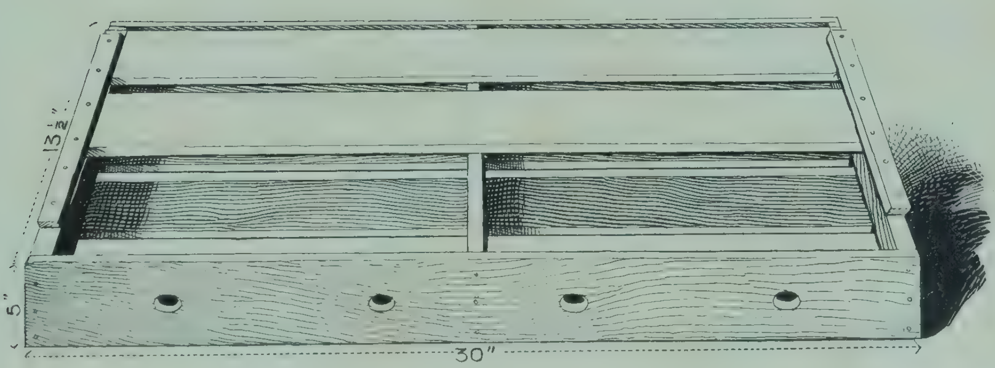

Fig. 2.

Plate II.—Crates for Avocadoes. The measurements are outside dimensions.

though it may be impossible to discover any evidences of it when the fruit is first picked. The fruit must be gathered by hand and the stems should be cut with a pair of shears as oranges are picked. If pulled the stem is likely to pull out from the fruit leaving a place where decay is sure to start. There is also danger of injuring the tree for if the stem is not cut at the proper place the branch may be broken too far back. Therefore, the cut should be made just above the natural joint found between the fruit stem and the branch.

The picking should be done on the day when the steamer is to sail or the day just preceding, if the sailing is in the morning. The experiments made, do not indicate that picking several days previous to sailing and placing in cold-storage is likely to be advisable. The reason for this is not far to seek. Though the fruit may be transferred without delay from cold-storage to the ship, the refrigeration compartments of the ship are open for the reception of freight and are not at a low temperature. The fruit therefore becomes warmed, and nothing will destroy fruit more rapidly than alternating variations in temperature. When the business assumes sufficient proportions to justify a steamship in devoting one compartment exclusively to fruits coming from cold storage, early picking and storing would be feasible.

Grading. Careful grading is important. Nothing detracts more from the appearance or the selling price of good fruit than does poor grading. The few unusually large and fine fruits from a given lot if picked out and packed by themselves will generally sell at a fancy price. If they are put in the same package with average fruit, not only is this special price lost but by contrast they make good average fruit look poor and thus lower its price to that of inferior goods. Fruit that is rather second grade if neatly packed will often bring a reasonable price, but if placed with good specimens will destroy the whole package. As illustrative of this principle the following experience may be related. A grower shipped to Honolulu a small quantity of limes to be sold at the auction rooms. A Honolulu business man realizing the importance of sorting and neatness in packing, purchased these limes at auction paying $1.50 for the lot. He also purchased a few fruit baskets in which to pack them. The limes were washed and sorted into four grades before being placed in the baskets. They were then placed on the market at twenty-five cents per basket, and sold readily. The account as furnished by the gentleman above mentioned stood as follows:

Purchase price of limes	$1.50
Baskets	.25
3 hrs. labor, boy and help	1.00
Total expense	$2.75
Sale of 38 baskets limes at 25c. per basket	$9.50
Deducting costs	2.75
Profit	$6.75

This only illustrates what may be accomplished by proper grading and packing, and what is constantly being lost by careless methods of packing.

The fruits in a package must be uniform in size, form, color, and other characters. Otherwise they will not sell for a good price.

To do the grading and packing properly it is very desirable that there should be a packing house. A room, or even a part of a room, will do where the business is small, but some place properly equipped and of suitable size should be devoted to this work. The chief essentials in the construction or selection of such a room are coolness, good ventilation and convenience of approach. In equipment it is important that everything be arranged systematically so that the packer may have crates, crate covers, wrappers, nails, and all the essentials within easy reach from his position in front of the packing table.

Packages. A second error which has been made, is in the packing. The fruits have been placed in too large boxes. The writer has seen avocados arrive in the San Francisco market in boxes as large as potato crates. This makes too much pressure on the fruit. An unnecessary amount of heat is generated and the fruit begins to ripen before it can be cooled in the refrigeration. A crate which was found to be very satisfactory for medium sized fruit was of the following dimensions: 13 inches by 14 inches by 3¾ inches, inside measurement. Such a crate (Plate II, Fig. 1) requires the following materials:

2 pieces ¾″ by 3¾″ by 13″ for ends,

2 pieces ¼″ by 3¾″ by 15½″ for sides.

6 pieces ¼″ by 3″ by 15½″ for tops and bottoms,

2 or 4 pieces ¼″ by ¾″ by 11¼″ for cleats.

The cleats may be put on the top and bottom, or on the top only. This crate holds about one dozen avocados of average size. A convenient crate of double this capacity (Plate II, Fig. 2) is made of the following materials:

2 pieces ¾″ by 3¾″ by 13″ for ends,
2 pieces ¼″ by 3¾″ by 30″ for sides,
6 pieces ¼″ by 3″ by 30″ for tops and bottoms,
1 piece ½″ by 3¾″ by 13″ for partition,
3 or 6 pieces ¼″ by ¾″ by 11¼″ for cleats.

The advantage of the cleats is in providing an air space between the boxes. They also aid in holding on the slats. Both of these crates, it will be seen, take only a single layer of fruit. For large sized fruit the depth must be increased to at least four inches. A slight adjustment to the depth of the crate can sometimes be made by tilting the pear and supporting it in this position by the adjacent fruit.

Wrapping and Packing Materials. Each fruit should be carefully wrapped in a piece of paper large enough to make a single covering and which has not been used for other purposes. Old newspapers and second-hand orange or lemon covers should never be used. A little excelsior above and below the fruit may be used but appears to be unnecessary and gave some indication of being injurious. A few fruits which were shipped in individual compartments made of crimped or corrugated straw-board arrived at their destination in excellent condition but scarcely better than those wrapped simply in paper. One hundred and sixty-seven fruits packed in this simple manner with nothing but paper wrappings, arrived in Portland with a loss of only 2.9 per cent. Some fruits were packed in bottle covers of tule. These appeared to be wholly unsatisfactory and although they occupied more space, were far more expensive and less attractive; the fruits packed in them showed a loss of 71.4 per cent.

Placing the fruits. The fruits should be placed as closely together as possible. It does not appear to be advisable to put them under as much pressure as is produced in the packing of some temperate zone fruits, for example apples, but there should be no vacant spaces and the fruit should be snugly packed together.

Conditions on Steamships. The degree of temperature which is best for the preservation of avocados has not been determined. This may be said to be true of most tropical fruits. It is not improbable that a temperature higher than that to

which temperate zone fruits are subjected, would be desirable. Experiments made by this Station and which are confirmed by reports from elsewhere, show that prolonged storage in temperatures such as are used for peaches, grapes, plums, etc., results in the blackening of the interior of the avocado. These temperatures appear to be endured without injury for about three or four weeks. It is recommended that the mercury should not fall below 40° F. It is important that the room on the ship should be cooled as rapidly as possible so that the fruit will immediately give off its heat and a uniform temperature should be maintained throughout the voyage. If through inattention the mercury should long remain below 40°, it would be at great risk to the fruit.

Shipping on deck without any refrigeration cannot be recommended for avocados. Of the several crates so carried on the voyage in question, none arrived in condition to be put on the wholesale market. Many of the fruits were over-ripe and all were fully ripened.

PAPAIAS.

Objects of the Experiment. The objects of the experiment were much the same as those outlined above, in the case of the avocados. It was first desired to determine whether the shipping of papaias is practicable and if so, to determine what methods will give the best results, what varieties are the best shippers and at what stage of maturity the fruit can be shipped. The papaias were subjected to the same unusually trying conditions as described above in the case of avocados. It should be remembered that this was not a commercial venture, for no one acquainted with perishable fruits would think of shipping such, six days in refrigeration followed by two days through extremely warm weather by ordinary express.

Results of Experiment. The results of the different trials are shown in the following table:

Plate III.—Young Papaia Tree of the Long Variety.

TABLE VIII. *Results of experiment in shipping papaias.*

STYLE OF PACKING	Sound	Unsound ..	Loss, per cent. ...
LOT A. Round fruit, green but full grown; wrapped in glazed paper, packed on ends in excelsior and one tier deep	18	5	21.7
LOT B. The same as "Lot A," but beginning to ripen, as indicated by slight tinges of yellow.....	14	8	36.3
LOT C. Round fruit, full grown but green, wrapped in porous paper and packed on sides in rice chaff in a tight box and headed without any pressure ..	13	5	27.7
LOT D. The same as "Lot C," except fruit beginning to ripen, as indicated by slight tinges of yellow...	14	11	44.
LOT E. Mature fruit of the long type, wrapped in glazed paper and packed one tier deep in flat crate and with excelsior..............................	37	3	7.5
LOT F. Mature fruit the same as "E," except wrappped in porous paper	30	20[1]	40.
LOT G. Mature fruit of the long type, wrapped in porous paper and packed six in a crate, each fruit being surrounded by wrapping of corrugated or crimped strawboard.[2] (Figure)................	50	10	16.6

Round versus Long Fruits. The fruit of the long type (Plate III) is better for shipping than the round. It chambers more readily, leaving less vacant space. It is difficult to pack round fruit of the size of papaias so that there will not be too much vacant space and too much motion of the fruit within the crate. The round fruit having a larger hollow space within, in proportion to the surrounding pulp is more likely to break down in ripening or to telescope if it is standing on the stem. By having crates varying slightly in dimensions and by cutting the stems reasonably long when the fruit is gathered and shortening it as required to fit the crate, the papaias of the long type pack very nicely, make a neat and attractive appearance in the crate and appear to withstand shipment better than the round forms. Wide variation in the length of the stems would not be permissible.

Green versus Tinged Fruit. At the present stage of the in-

[1] 16 out of the 20 were badly bruised.

[2] Such material as is used in the packing of glass preserve bottles.

vestigations in shipping papaias, it is recommended that fruit just beginning to show the indications of ripening by the presence of slight tinges of yellow, should be shipped to San Francisco or other port which is reached by immediate journey. It is not to be recommended at present that such fruit be used where transhipment would be required. Commercial shipments in the immediate future, should be confined to markets reached by direct journey from Honolulu, Hilo, or other Island ports. The fruit that is gathered green where there is no indication of yellowing, does not acquire as fine a color as that which has just begun to ripen on the tree, though it will become ripe and marketable if fully grown.

Paper for Wrapping. Referring to Lots "E" and "F" in Table VIII, it will be seen that there was a very heavy loss on the fruit wrapped in porous paper. These results, however, are modified by the fact that sixteen out of the twenty unsound fruits in lot "F," were badly bruised. This is one of the factors which does not admit of explanation and must be regarded as purely accidental so far as the wrapping is concerned. It certainly bears no relation to the fact that the fruit was wrapped in porous paper. Even excluding the sixteen bruised fruits, the percentage of loss on papaias wrapped in porous paper is rather larger than on the fruit wrapped in glazed paper but the difference is so slight that no conclusions could be based on these results. For the present, it is recommended that glazed paper be used. It does not so readily communicate moisture from fruit to fruit as unglazed wrappers and has given the best results as a wrapper for some other fruits.

Crimped Straw-Board. The use of crimped straw-board as an exterior wrapper to go about each fruit in addition to the paper wrapping, is recommended. This provides a very valuable elastic cushion against which the fruit rests and which saves the fruit much bruising. Crimped straw-board is not expensive and may be purchased by the roll or cut in sizes to fit the fruit. The strips should be a little narrower than the length of the fruit, to allow of good ventilation and should be long enough to encircle the average fruit and slightly lap at the edges.

Refrigeration. Refrigeration can be recommended for the shipping of papaias. No deterioration in the flavor of the fruit

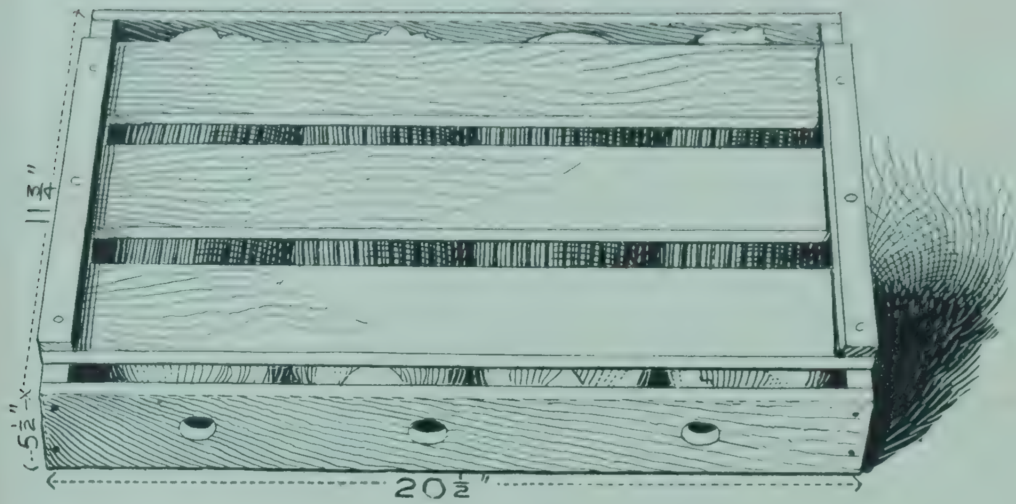

Fig. 1.

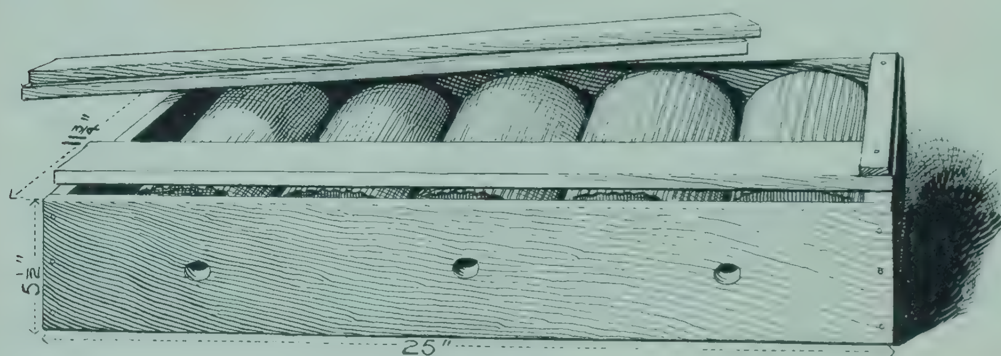

Fig. 2.

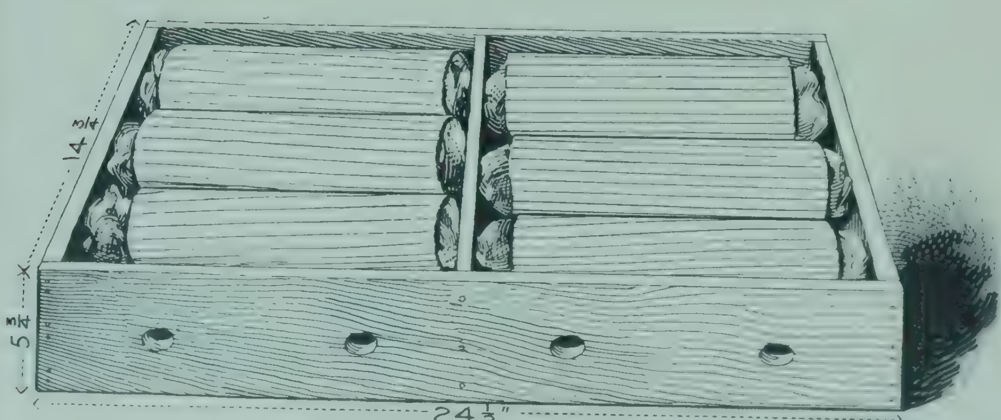

Fig. 3.

Plate IV.—Crates for Papaias. The measurements are outside dimensions.

could be detected after it had been in refrigeration throughout the voyage to San Francisco; nor were there any other evil effects apparent.

Crates. Only flat crates containing one layer of fruit should be used. The sizes described below are found to be convenient and are recommended for further trial. These are essentially the same dimensions as shown in Plate IV, but are made of lighter material. These are for rather large fruit.

Crate to hold 4 papaias (Long variety).

Dimensions 5½" by 11¾" by 20½".

Materials

2 pcs. ¾" by 4¼" by 11" ends,
2 pcs. ⅜" by 4¼" by 20½" sides.
6 pcs. ⅜" by 2½" by 20½" tops and bottoms.
2 or 4 pcs. ¼" by ¾" by 9½" cleats.

Crate to hold 6 papaias (Long variety).

Dimensions 5¾" by 14¾" by 24½".

Materials

2 pcs. ¾" by 4½" by 14" ends,
1 pc. ¼" by 4½" by 14" partition,
2 pcs. ⅜" by 4½" by 24½" sides,
6 pcs. ⅜" by 3½" by 24½" tops and bottom,
2 or 4 pcs. ¼" by ¾" by 12½" cleats.

Market Prospects. Observing the above recommendations and being extremely careful to handle the fruit with the utmost care to avoid bruising, there will be no difficulty about shipping papaias to any direct Coast market. The papaia was found to meet with favor among those who ate it even for the first time in the markets visited during the past summer. A ready market could be made for papaias in any of the Pacific Coast cities and especially in the season when muskmelons are not plentiful. Only first class specimens should be shipped. To send insipid, worthless papaias would do great injury to the whole future industry.

BANANAS.

Source of Supply.

Excepting San Francisco, practically all the markets visited and in fact the whole of the Pacific Coast is supplied with bananas from the East. These are spoken of as the "Eastern" bananas or the "New Orleans" bananas because they are ship-

ped through New Orleans. The fruit is grown chiefly in Central America and is shipped in steamers owned and controlled by the owners of the fruit and discharged at New Orleans. Here they are loaded into cars containing about three hundred and forty bunches and are trans-shipped by rail to the entire West. As has been stated elsewhere, the fruit is sold on order. The agencies in New Orleans, by telegraphic advices, know exactly what fruits are required, what are on the way to New Orleans and what are obtainable. The prices quoted for these differ according to the quality of the fruit. Prices are quoted by the name of the port from which the bananas are shipped but they are all of the Jamaica or Martinique variety. For the week beginning June 16, 1906, they were as follows:

Limon	$2.40	per cwt.
Changuinola	2.30	" "
Bluefields	2.20	" "
Chiriqui	2.20	" "
Barrios	2.20	" "
Ceiba	1.90	" "

The cars containing bananas are sent through by fast freight and are accompanied by an attendant who is an employee of the company shipping the fruit and whose business it is to look after the interests of the fruit in transit, opening or closing the ventilators as required by varying climatic conditions, in order to maintain a uniformly cool temperature. In the hottest weather refrigerator cars are used, but simply for cooling, since low temperatures destroy bananas. The freight rate which the buyer pays for transportation from New Orleans to any port on the Pacific slope, be it Los Angeles, San Francisco or even Vancouver, B. C., is $1.25 per hundred weight. On the average the cost of the freight, and other charges brings the price to the wholesaler, to approximately 4½ cents per pound for the best fruit.

San Francisco receives bananas from Hawaii, from the East and a few from Mexico. From Hawaii there are shipped to San Francisco approximately 15,000 bunches per month. Only a few bananas are received from Mexico. There are two or three banana plantations in Mexico owned or controlled by San Francisco capital and which ship bananas to that market. These fruits are of the Chinese variety and are in some respects fine bananas. They usually open up with a clear yellow rind if the shipping has been at all satisfactory. This is due to

Plate V.—Young Papaia Orchard Coming into Bearing.

comparative freedom from ripe rot disease or banana anthracnose, *Glœosporium musarum*, Cke. and Massee, which is the cause of the black speckled condition of some bananas. The Mexican bananas are affected recently with a disease which appears to be more serious than the ripe rot; it affects the stem of the bunch causing it to decay, which decay extends into the stem of the individual fruits causing them to drop from the bunch with blackened ends. The main stem may break off midway of the bunch so that the whole bunch goes to pieces. This disease, however, can probably be controlled and Hawaii must reckon upon Mexico as a competitor in the market.

Comparing the Chinese variety from these Islands and the varieties with which they come into competition in San Francisco (Plate VII), it may be said that no banana in the market is superior in point of flavor to those from Hawaii. If they arrive in good condition they find a ready market. It is a well recognized fact that the best class of trade in San Francisco calls for the bananas from Hawaii. Here their good qualities are known and recognized. It must be said, however, that growers in Hawaii have acted against their own interests, in shipping inferior bunches. As fine bananas can be produced today as were ever grown here if intelligence and care is brought to bear upon every detail of the industry. The cost of production of a small bunch is nearly as great as for a large one. The freight, which represents about one-third of the selling price of a good bunch, is precisely the same figure for the smallest bunch shipped. A small bunch is difficult to sell at any price and often does not bring enough to pay the 40 cents freight. A dealer who handles a very large number of the Hawaiian product has made the statement that Hawaii would practically supply the whole San Francisco market, if such bananas were shipped as formerly. The Chinese banana, however, is not so good a shipper as those of the Jamaica or Central American variety with which they come in competition. The Hawaiian bananas are wrapped in leaves and sometimes in straw, while those from the East are shipped without any wrapping. One of the steamship companies has offered to coöperate in an experiment in the shipping of bananas from Honolulu without wrapping. If this can be accomplished it will save an expense of approximately 5 cents per bunch for wrapping. It may cause a more careful handling of the fruit by all parties, from the plantation to the wholesale warehouse and it may also allow a better circulation of air to the fruit in the ship.

MARKET POSSIBILITIES.

Exclusive of Hawaiian bananas, there are shipped to the Pacific Coast, approximately 1,900 carloads of bananas per year. This includes those supplied to Arizona and New Mexico through Los Angeles; those to California, Oregon, Washington, British Columbia, Montana and Idaho. A carload averages about 340 bunches, making a total of 646,000 bunches per year consumed within this territory, exclusive of bananas from Hawaii. This is the equivalent of approximately 53,833 bunches per month. If these bananas were grown in Hawaii within the territory of the United States, they would represent an annual value of over half a million dollars to this Territory directly. In addition to this, they would supply the chief freight to two steamers making regular trips between the Islands and the mainland. All the markets west of the Great Plains might be supplied with bananas grown here on United States soil. The importance of this trade in the future may be estimated from the fact that the annual consumption of bananas in the United States is and has been increasing at the rate of more than one million dollars per year in value. From an agricultural and economic point of view there is no good reason why the Pacific Slope trade in bananas should not be supplied from Hawaii.

COOKING BANANAS.

The cooking banana is in its use so unlike the banana which is eaten without cooking as to be quite a distinct product upon the market. During the past twenty years, as has been seen, a large trade has been built up in the banana which is eaten raw. The cooking banana which takes the place of fresh vegetables and cooking fruit has not as yet been introduced to the American markets, except in New Orleans and about the Gulf Coast. There can be no doubt that during the winter season when there is a lack of fresh vegetables in the markets, there would be large demand for the cooking bananas that are grown now in a small way in Hawaii. The merits of the Hawaiian cooking bananas are but little understood even by a large number of people who have resided in the Islands for a considerable period. To the people of the mainland they are practically unknown. Active efforts to introduce and acquaint the people with this fruit could build up a large trade in these fruits.

Plate VI.—Old Papaia Orchard.

MANGOES.

The mango will unquestionably become a popular fruit in the markets of the temperate zone. Its beauty of form and coloring, its enchanting aroma and delicious flavor make it a fruit universally appreciated where known. The inferior seedling varieties have been responsible for the unenviable reputation which it has acquired among some travelers. The fine varieties have only recently been introduced in the American tropics and are as yet known to but few. When these shall have been propagated and widely distributed in Hawaii, Florida, Porto Rico, the Philippines, Cuba and Mexico, the growing of the fruit will become an important industry. The demand for it will increase as those who are yet young have seen the markets increase in their capacity for oranges, lemons, pomelos, bananas and many other fruits. Hawaii should grow a large portion of the mangoes for the Western markets.

In the shipments of August, 1906, no mangoes were included. The Station has, however, experimented for several years in the keeping of mangoes in cold storage with most favorable results. Mangoes may be kept much longer than avocados under refrigeration without deterioration in quality. They have been shipped long distances and have arrived in perfect condition.

There is but one obstacle to the development of a large and prosperous mango industry in Hawaii and this one calls for immediate and stringent action on the part of the Government. The mango-weevil, *Cryptorhynchus mangiferæ* threatens the industry and the longer the fight against it is delayed the greater will be its difficulties and expense. It is a short sighted and suicidal policy to withhold immediate action even if its cost should be great.

SWEET POTATOES.

The shipping experiments included only fruits but a study of the markets revealed a promising opening for the shipping of sweet potatoes from Hawaii to the mainland during the time when those grown there are out of season. Almost all of the sweet potatoes used on the Pacific Coast are grown in California. The opening of the season is about the middle of August and it continues until about April 15th. When they first appear on the market the prices are very high, $60. to $80. per ton wholesale being not an uncommon price. During

the latter part of the season the potatoes which have been stored for a long time are of indifferent quality. The time when the Hawaiian product could probably be put on the market at high prices would be from April 15th or earlier, until August 15th.

All these markets at the present time, demand a white or light yellow potato of medium size and dry. The red varieties are almost unknown and though it might be possible in time to place some of our best red varieties, it must be done gradually. The people know the yellow potato and in this case it is much more profitable to grow what the people want than to make the people want what you grow.

The standard crate in which potatoes are shipped in California, contains about one hundred pounds. The ends are 18 by 11¾ inches and are one inch thick. The side slats are 2 feet long and are of ¼ inch lumber. This would be a suitable crate in which to ship from Hawaii. Sacks should not be used.

MARKETING SYSTEM.

Fruit and all agricultural products have in the past been marketed by the commission and consignment system. This system is too common today. By this method the grower ships his fruit to a distant city consigning it to a commission merchant and says in effect "Sell for me these products at such prices as you can secure, take your commission and return to me what is left." Such a method of marketing is manifestly unbusinesslike and does not prevail in the world of commerce except in the handling of agricultural products. Does the manufacturer of shoes or household furniture or any other commodity take great pains in the production of the finest possible manufacture and then ship his goods to a commission merchant with the request that the goods be sold and that whatever may be due him after the transactions are closed, be remitted? Granting that he is assured of the highest integrity on the part of the commission house, he does not care to market his product in this manner. Men in the fruit commission business are as honest as in other lines of enterprise, yet it will be admitted that this system offers unusual opportunity for unscrupulous dealing and it is hardly to be expected that the whole fraternity of commission men will be without an exception, in straight dealing and integrity. For this reason if for no other, the grower should seek other methods of marketing, for many losses will be sustained while the grower

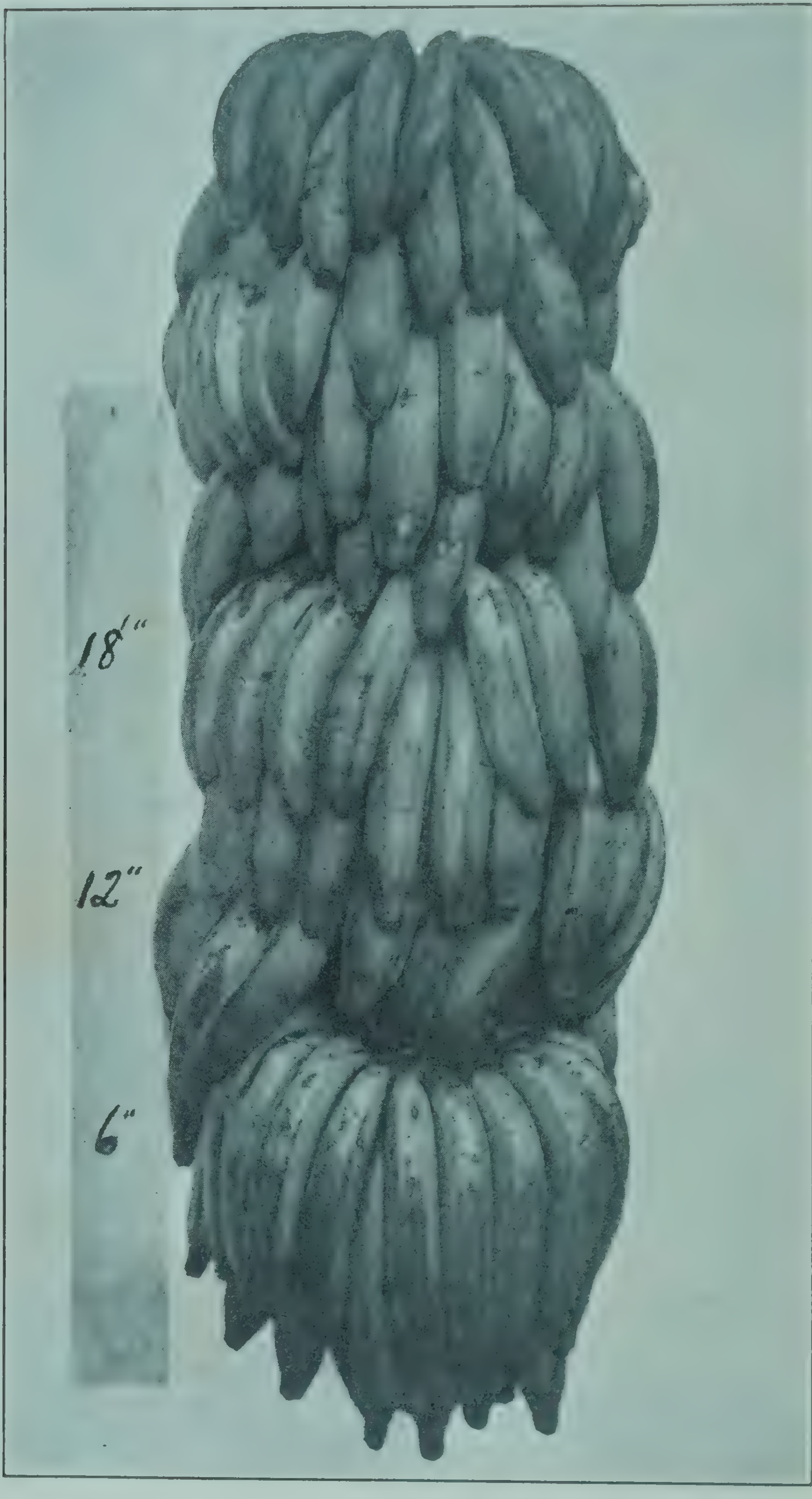

Plate VII.—The Jamaica or Central America Banana.

is finding a man in whom he can rely to do the best for him which this system permits.

There are, however, other reasons for condemning this system. The interests of the commission house lie in exactly an opposite direction to that of the producer or shipper. Manifestly the interest of the commission house lies in the direction of commissions. Much more money can frequently be made in the form of commissions, on fruit selling at a low than at high price. It is of course to the advantage of the shipper that the fruit be sold at the highest possible price. At first sight it may appear that this will also be to the best interest of the commission merchant, but it is not the case. Low prices mean many sales and an easy market, high prices mean fewer sales. As prices drop, the sales increase very rapidly. Suppose for example, that a pineapple grower in Hawaii ships to San Francisco one hundred dozen pineapples. If these are all sound and sell at $4. per dozen the account not considering minor charges should stand as follows on a 10 per cent. commission basis:

100 doz. pineapples at $4....................	$400.00
Commission at 10 per cent..................	40.00
Remittance to grower................	$360.00

Suppose the same pineapples should be put on the market at $3. per dozen the account would stand:

100 doz. pineapples at $3....................	$300.00
Commission at 10 per cent..................	30.00
Remittance	$270.00.

By this fall in prices the shipper has sustained a loss of $90. and the commission merchant an apparent loss of $10. Provided, however, that there is a sufficient supply of pineapples available, this loss of $10. is only an apparent loss. By selling thirty-three and one-third dozen more pineapples, the $10. is made up. This difference of $1. per dozen in the price will increase the sales far more than 33 1-3 per cent. so that the commission house has really profited by this low price and has not lost. The larger the volume of trade as a general rule, the larger will be the net income of the commission house. It will be granted that the commission house will wish to do the best possible for the man who consigns to it, provided that in so doing its own business interests are not interfered with, be-

cause it wishes to please him and secure his future business, but the fact remains that its interests are in the line of large sales even at low prices and would frequently be interfered with by doing the best possible for the shipper. Greater activity in distribution might dispose of the supposed one hundred dozen pines at $4. per dozen, but would it pay? From the standpoint of the owner of the fruit it would, but from the point of view of commissions, it might not. If not, who will charge the commission merchant with anything other than honorable business dealings when he sells at $3. per dozen? If the careful distribution at the higher price costs him more than the $10. it would be akin to philanthropy for him to maintain that figure. The fault is not with the men but with the system.

It must further be admitted that the care in handling which fruit receives in being taken from the ship to the store rooms will be greater if performed by or under the supervision of the owner of the fruit. This again is saying nothing derogatory of the commission merchants but nobody expects another party to look after his interests as well as he, personally, or through his agents, could do. Business is not done on this plan. For example the writer has seen bananas from Hawaii loaded on wagons on the docks in San Francisco being placed five or six tiers high and the men loading the fruit walking over the lower bunches while reaching to place other bunches on the higher tiers. When these bunches begin to ripen the bruises which have been caused by being walked upon and by the deep stacking, are very apparent and probably a large portion of the bunch is worthless. These bunches have to be sold for almost nothing and returns are made to the shipper for so many bunches spoiled. Probably the managers of the houses for whom these draymen were working would not approve of the fruit being treated in this manner, but if the ownership of the fruit were transferred to the commission house and the destruction of each bunch represented a dollar or two to them, no one will dispute that the incentive to enforcing proper handling upon those driving the fruit wagons, would be greatly increased. In other words, the commission house makes cash returns for only the fruit that is opened up at its show rooms in fit condition for sale and so remains until a sale has been made.

In other lines of commerce, goods are sold on order. The owner or his agent interviews the buyers and secures orders

Plate VIII.—The Chinese or Cavendish Banana as grown in Hawaii.

from each. Is there any good reason why the fruit growers of Hawaii should not sell their fruit on this plan? It is business-like, it avoids glutting the markets and provides for a far more general and wide distribution than the system described above. This is the method which is pursued by the competitors of Hawaii in the banana and pineapple markets. Those who control the "Eastern" bananas sell to a given commission house in San Francisco, Seattle, Portland or other market, a carload of bananas at a given price f. o. b. New Orleans. This fruit then becomes the property of the Pacific Coast firm which, in the transaction, acts not as a commission house, but as a wholesale dealer in fruits. Pineapples from Florida, which compete with the Hawaiian product, are sold in the same manner as these bananas. The different wholesale dealers unite in ordering a carload when one firm cannot handle that quantity but they are sold in Florida to be shipped to the West and ownership in the fruit is there transferred to the different firms who buy.

This method of disposing of fruit is growing in favor. Nothing further need be said to show that it is far more desirable for the producer than the commission system. It is also satisfactory to the commission merchants who are to a large extent at the present time, wholesale dealers in fruit, which they buy and sell in the same manner as any other commodity. A very large portion of their business is done in this way. Provided the fruit is up to the standard, well packed, sold at a reasonable price, and arrives in reasonably good condition, this method cannot fail to give satisfaction to those who buy at wholesale.

In order that such a plan may be carried out to the best advantage, it is important that the Hawaiian fruit growers should organize for the marketing of their product. By so doing, an agent on salary and wholly responsible to them, could be maintained in San Francisco who could for the present attend to the taking of orders on the Pacific Coast. This being his exclusive business he could without a doubt, place large quantities of fruit in cities and small towns where our fruits are scarcely known. This would not necessitate the establishing of a wholesale fruit house, for the fruits could go, as now, to the wholesale dealers. Another agent should be appointed to attend to the proper shipping of the fruit from

Honolulu, who need give only a part of his time to this work. This plan need not entail much expense and would certainly save to the growers and shippers, a sum far in excess of that expended.

The fruit growers of California have organized themselves into very strong combinations conspicuous among which are the California Fruit Exchange and the California Fruit-Growers' Exchange, the former for the handling of deciduous fruits chiefly, and the latter for citrus fruits. These two bodies now market a very large portion of the fruit of the State. Their agents are in every important market in the United States and keep the growers and shippers informed by telegraphic advices as to prices and the general condition of the markets.

The Hawaiian growers could doubtless avail themselves of the advantages of this whole California system if an organization could be effected along the lines followed by the local associations throughout California. These local associations together constitute the central organization. In conversation with Mr. A. R. Sprague, President and Manager of the California Fruit Exchange, the writer was assured that it would be possible for an association in Hawaii to be taken into the general organization on the same basis as the local branches in the different parts of the State. This opportunity is well worthy of consideration by those interested in Hawaiian fruit industries.

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HAWAII AGRICULTURAL EXPERIMENT STATION.

J. G. SMITH, SPECIAL AGENT IN CHARGE.

BULLETIN No. 15.

CULTIVATION OF TOBACCO IN HAWAII.

BY

JARED G. SMITH,
SPECIAL AGENT IN CHARGE OF HAWAII EXPERIMENT STATION,
AND
CHARLES R. BLACOW,
IN CHARGE OF TOBACCO INVESTIGATIONS.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
U. S. Department of Agriculture.

WASHINGTON:
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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JARED G. SMITH, *Special Agent in Charge.*
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J. EDGAR HIGGINS, *Horticulturist.*
F. G. KRAUSS, *In Charge of Rice Investigations.*
Q. Q. BRADFORD, *Farm Foreman.*
CHARLES R. BLACOW, *In Charge of Tobacco Experiments* (*P. O., Paauilo, Hawaii*).
ALICE R. THOMPSON, *Assistant Chemist.*

LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 1, 1907*.

SIR: I have the honor to transmit herewith, and recommend for publication as Bulletin No. 15 of this station, a paper on the Cultivation of Tobacco in Hawaii, prepared jointly by myself and Mr. C. R. Blacow. The paper embodies the results of three years' work with this crop in an attempt to demonstrate the possibility of its production on a commercial scale in Hawaii. The small crop produced in 1904 showed excellent characteristics, and these have been greatly accentuated in each succeeding crop. The tobacco is of mild flavor, good burn, elasticity, and texture, the Sumatra and Cuban type of wrapper leaves showing qualities similar to those produced in the best tobacco districts of those countries, so that there is now no question that the industry can be established on a commercial basis.

A point of interest which has not been touched upon in the body of the bulletin is that a few plants from Turkish tobacco seed which came from Asia Minor produced leaf having the characteristic flavor and aroma of this well-known type, and it is believed that considerable areas of land in Hawaii are suitable to the production of this and other scented tobaccos.

Respectfully,

JARED G. SMITH,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, *Washington, D. C.*

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

CULTIVATION OF TOBACCO IN HAWAII.

INTRODUCTION.

The requirements of skill and knowledge attendant upon the curing, fermentation, handling, and marketing of tobacco make the cultivation of this crop one of the most desirable for inculcating thrift as well as modern methods of agriculture. The districts where the soil and climate are adapted to the production of cigar-leaf tobaccos of high grade are limited. For that reason the market for the product is always a good one. While tobacco is, perhaps, strictly speaking, a luxury, it is one of world-wide use among all nations and all classes of people. As in the case of all other luxuries, stimulants, or narcotics, the ratio of consumption depends somewhat upon the prosperity of the people who use it. Tobacco is always salable, but its price rises and falls in accordance with world-wide conditions as affecting the supply of the weed and the purchasing power of the consumer.

The production of tobacco in any country tends toward the building up of a stable population. The skill required is that of men who make its production their life-long occupation. A great deal of labor is required, and if the industry is to succeed here in Hawaii those who are identified with its development must people the land and bend their endeavor to the maintenance of a permanent, contented population.

The tobacco grown by the Hawaii Agricultural Experiment Station in the Hamakua district on the island of Hawaii has been pronounced by experts in the trade as equal in quality to that produced in any other tropical tobacco-growing country. It was believed before the work was begun that this and other districts were particularly adapted to the cultivation of this crop, provided modern methods were applied. Work was begun three years ago with the object of demonstrating the possibility of this crop. The work has been hampered from the beginning by insufficient funds, but the results amply repay for the struggles and hardships. Mr. C. R. Blacow has had entire supervision of the work, under the direction of the special agent in charge, since June, 1905, and the success of

the demonstration has been due to his constant efficiency. Acknowledgments are due to Mr. George P. Thielen, James B. Castle, J. P. Cooke, George N. Wilcox, and A. S. Wilcox, who came to the assistance of the station at a very trying financial period, and contributed \$4,000 toward the cost of building a new tobacco barn, and for the payment of other necessary expenses in connection with the experiment. Early in 1906 the land commissioner of Hawaii, Hon. James W. Pratt, reserved from entry for the use of the station, for the purpose of this experiment, lot No. 17, Paauilo homesteads (Pl. I, figs. 1 and 2), this reservation to hold for three years if desired to maintain a demonstration field during that period. The legislature, in 1905, appropriated a sum equal to \$228 per month for assistance. A large part of this fund was used for the tobacco work. The remaining portion of the expenses of the experiment have been borne from the regular funds of the station.

Many experiments with the tobacco plant have been undertaken. Seed has been planted every week in the year, and plants have been set in the field in all seasons. Studies have been made of a number of types of Cuban, Sumatra, and domestic tobaccos, and much valuable data has been got together. The station has experimented on the type or style of tobacco barn best suited to Hawaiian conditions. It is believed that the one described on page 9 represents an improvement in the curing barn over any type of structure used in other tobacco countries. This preliminary work, if taken advantage of by anyone entering upon the cultivation of tobacco on a commercial scale in Hawaii, can be made to save a great deal of money.

Demonstration experiments of the possibility of the introduction of new crops are extremely expensive, and the funds of the station will not admit of carrying on these experiments upon the former scale. Some of the problems incidental to the successful growing of tobacco may be continued, but the station turns over to the people of Hawaii the results achieved and will leave to private enterprise the establishment and further development of the tobacco crop.

THE CURING BARN.

The curing barn should be built before planting operations are commenced. A group of buildings should be conveniently located, and here in Hawaii, where the slope of the land is steep, they should be erected at the lower edge of every 100 acres of planted land. Curing barns containing 10,000 cubic yards of space will be necessary for every 100 acres of tobacco, provided the structures are supplied with artificial heat, as should be done. If no artificial heat is provided, it will require buildings with from 18,000 to 20,000 cubic yards of space to care for 100 acres of crop. The buildings

FIG. 1.—LOT 17, PAAUILO TRACT BEFORE CLEARING ABANDONED COFFEE.

FIG. 2.—TOBACCO FIELD PLATS, PAAUILO.

should be of a permanent character. If properly built and provided with proper precautions against destruction by fire, the building should last for at least twenty years, and if properly cared for it will last for a much longer period. The barn should be placed at right angles to the prevailing winds. It is better to erect it on a sloping hillside, provided the slope of the land is toward the direction of the wind.

The curing barns should be frame structures, built of common sizes of northwest lumber. No timbers larger than 4 by 6 inches are required and these only for the sills. A shingle roof is preferable to an iron roof. The barn must be floored. The construction of the ground floor will be discussed later. The wall on the leeward side of the building should extend clear to the ground, also the two ends. This acts as a wind sail for forced draft. Ventilation should be almost entirely through the floor. The building should be from 22 to 24 feet from sill to plate (fig. 3) and 40 to 48 feet in width, with a gable roof. The gable ridge should have a height of 16 feet above the plate, irrespective of the width of the building. The wind-sail method of ventilation is rendered possible because of the uniform trade winds blowing almost continuously throughout the year. The experiment station has tried buildings with different systems of ventilation, and it is believed that for Hawaiian conditions the method here recommended is the best. The roof of the barn should be constructed with an open ventilator in the ridge. The cheapest and most practicable ventilator is the one which is figured in the accompanying plans (figs. 1, 2, 3, and 4); that is, the windward roof should project 3 feet over the lee roof, with a swinging door 18 to 24 inches in width the whole length of the building. This swinging door should be hinged on the bottom and an arrangement of ropes and pulleys provided so it can be opened and closed at will. No other ventilators are required in any part of the building. This applies to tobacco barns in the windward districts of Hawaii. In other localities not subject to the trade winds horizontal side ventilators of similar construction should be placed just below each of the stall floors.

If a single building with a capacity equal to 100 acres of crop is built, it should be divided into five compartments by partitions from the ground to the roof. Each compartment may be considered as a unit, and this unit construction may be followed for a single barn if it is decided to erect a number of smaller structures in separate localities rather than a single large one. There should be a 4-foot passageway down the middle of the whole length of the building, this passageway extending from the floor to the roof. Each unit should contain three double sets of hanging stalls on each side of the passage. The first floor should be solid, except that a ventilator—composed of two 1 by 6

inch boards, hinged on their outer edges, open from the center up-ward, an arrangement controlling the size of the opening and regu-

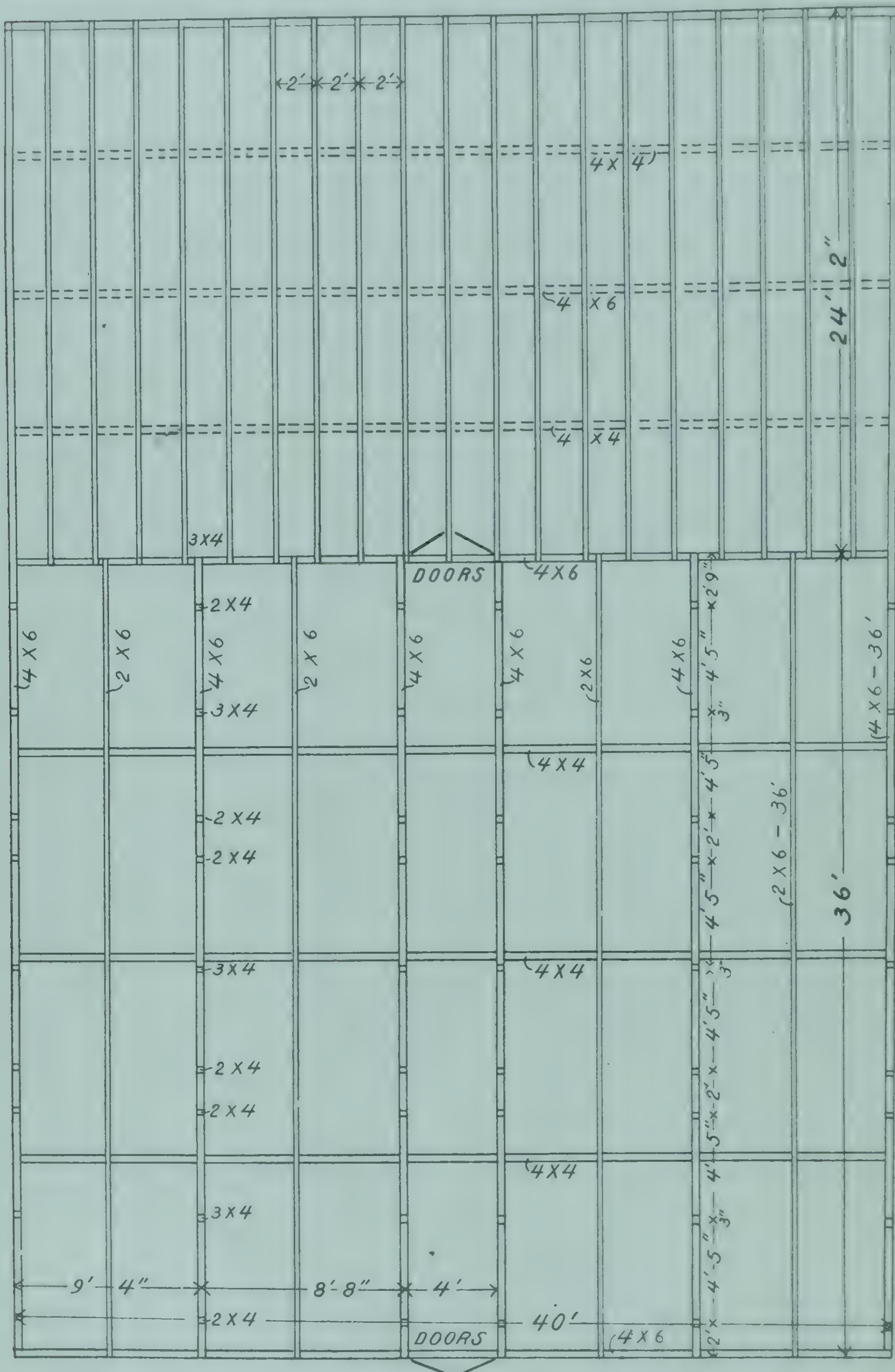

FIG. 1.—Ground plan of tobacco barn.

lating the draft—should be built immediately under the center of each tobacco stall. Starting at one end of the building a 2-foot alley

way is left next the end wall. Then two $4\frac{1}{2}$-foot skeleton stalls are framed of 2 by 4 inch stuff and four hanging rails at equal distances apart are nailed on the sides. Then there is another 2-foot passageway, and another double set of stalls, and so on to the other end of the building, finishing with a 2-foot passageway between the last

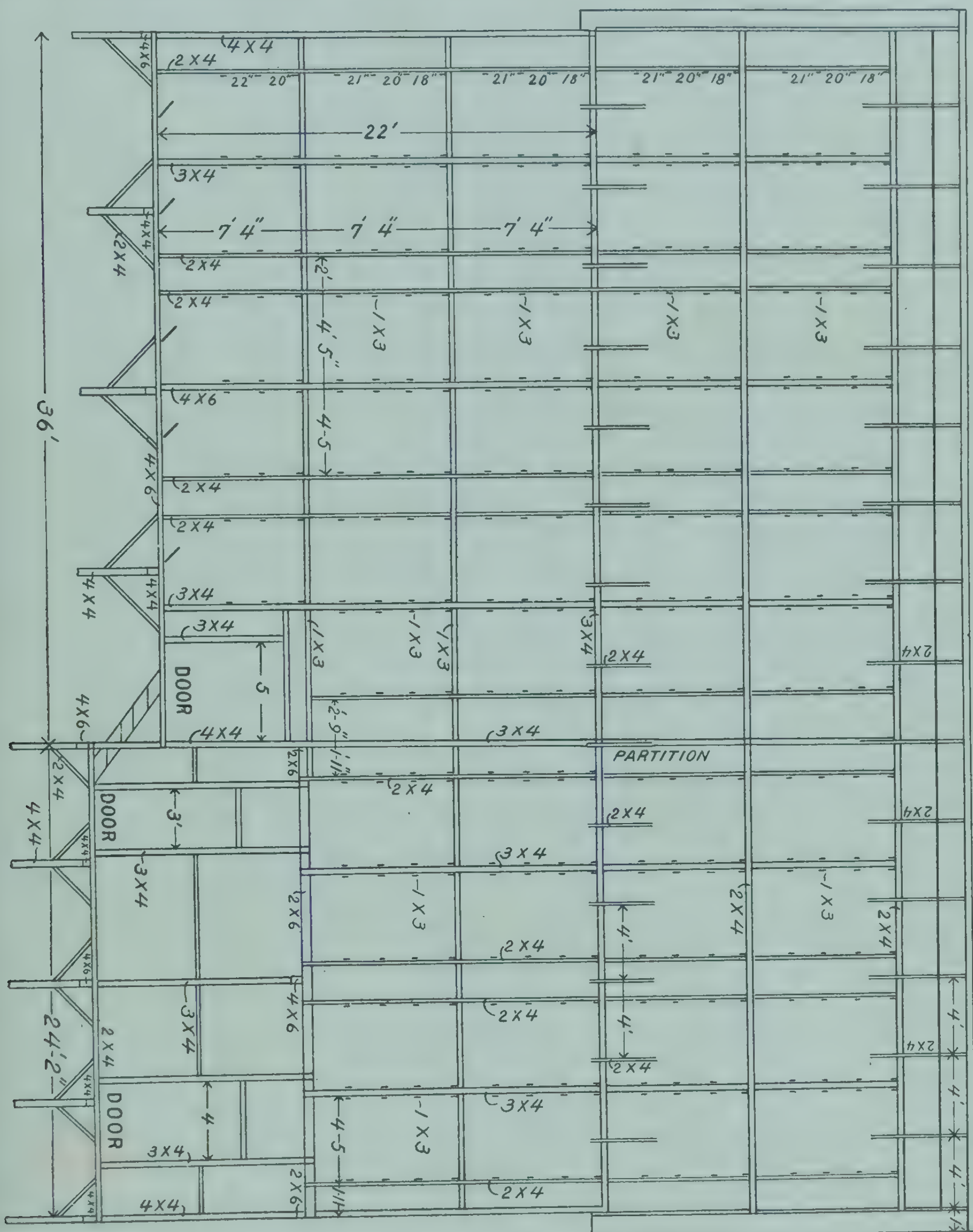

FIG. 2.—Side elevation of tobacco barn.

stall and the other end of the building or unit. These passageways between the double stalls are necessary in handling the tobacco. They also act as an aid to ventilation. The second and succeeding floors are all skeleton floors (fig. 4), which consist of a boarded passageway through the center of the building and a single 1 by 12

inch board laid in the passageway between the stalls and in the middle of each stall upon which the person hanging the tobacco walks. The height of the building is divided into three floors, with two floors in the gable. The floors can be connected by stairs or an elevator. Each unit should contain about 2,000 cubic yards of space. This size unit will accommodate the crop of from 5 to 6 acres of tobacco without artificial heat, which capacity is doubled if artificial

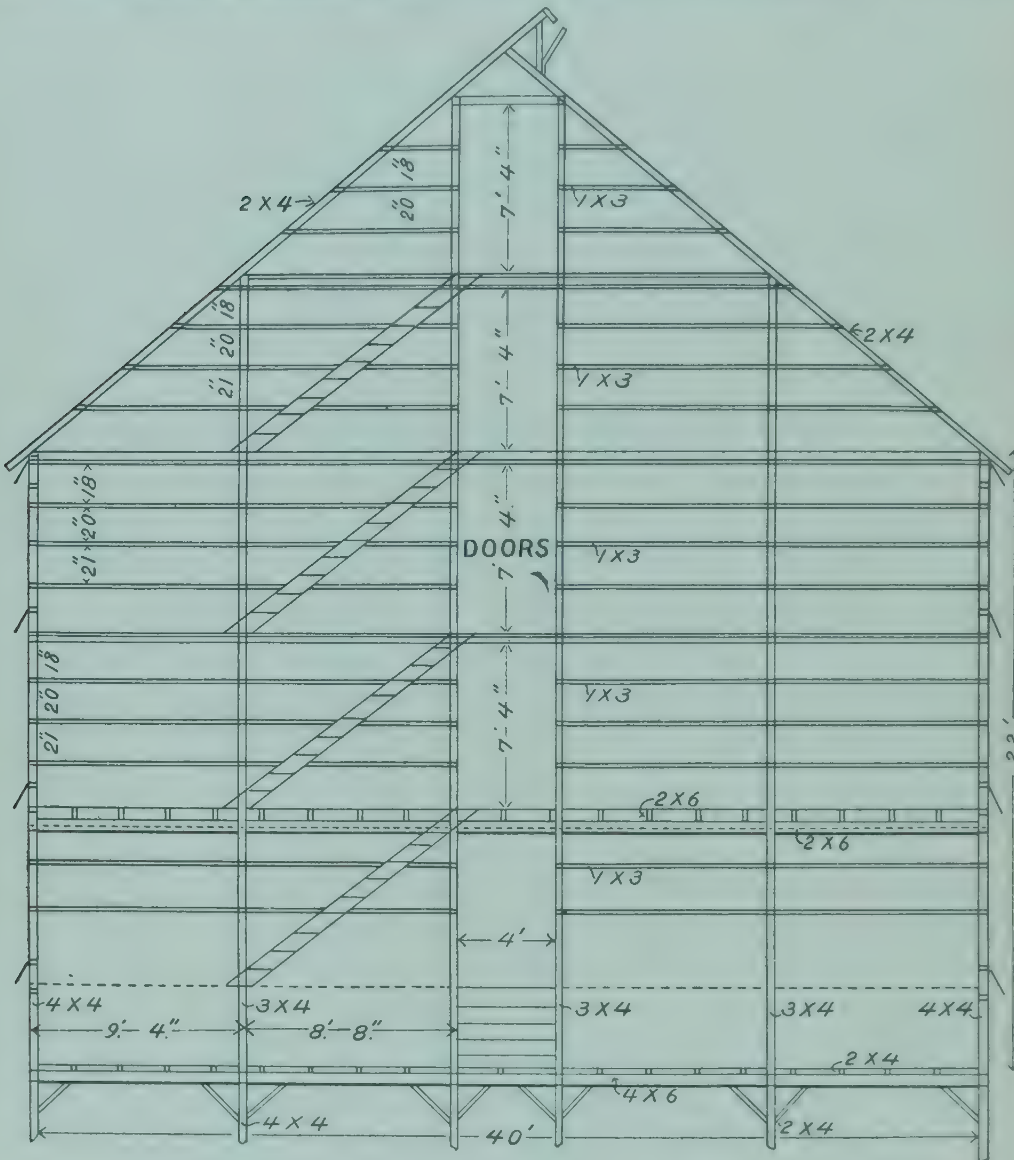

FIG. 3.—End elevation of tobacco barn.

heat is used; and, as about one-fourth of the crop is harvested at a picking, 5 units will care for 100 acres of crop with artificial heat, but 10 units will be necessary if no such heat is provided.

The heating plant should be hot water or steam, preferably the latter. Flue heating is not safe. There is danger of fire, and the heat is not controllable as in the case of either water or steam. The pipes should be placed on the first floor only.

In addition to the curing barn there must be a stringing room, which may be a lean-to of sufficient size, as experience will direct, attached to one end of the building (fig. 1).

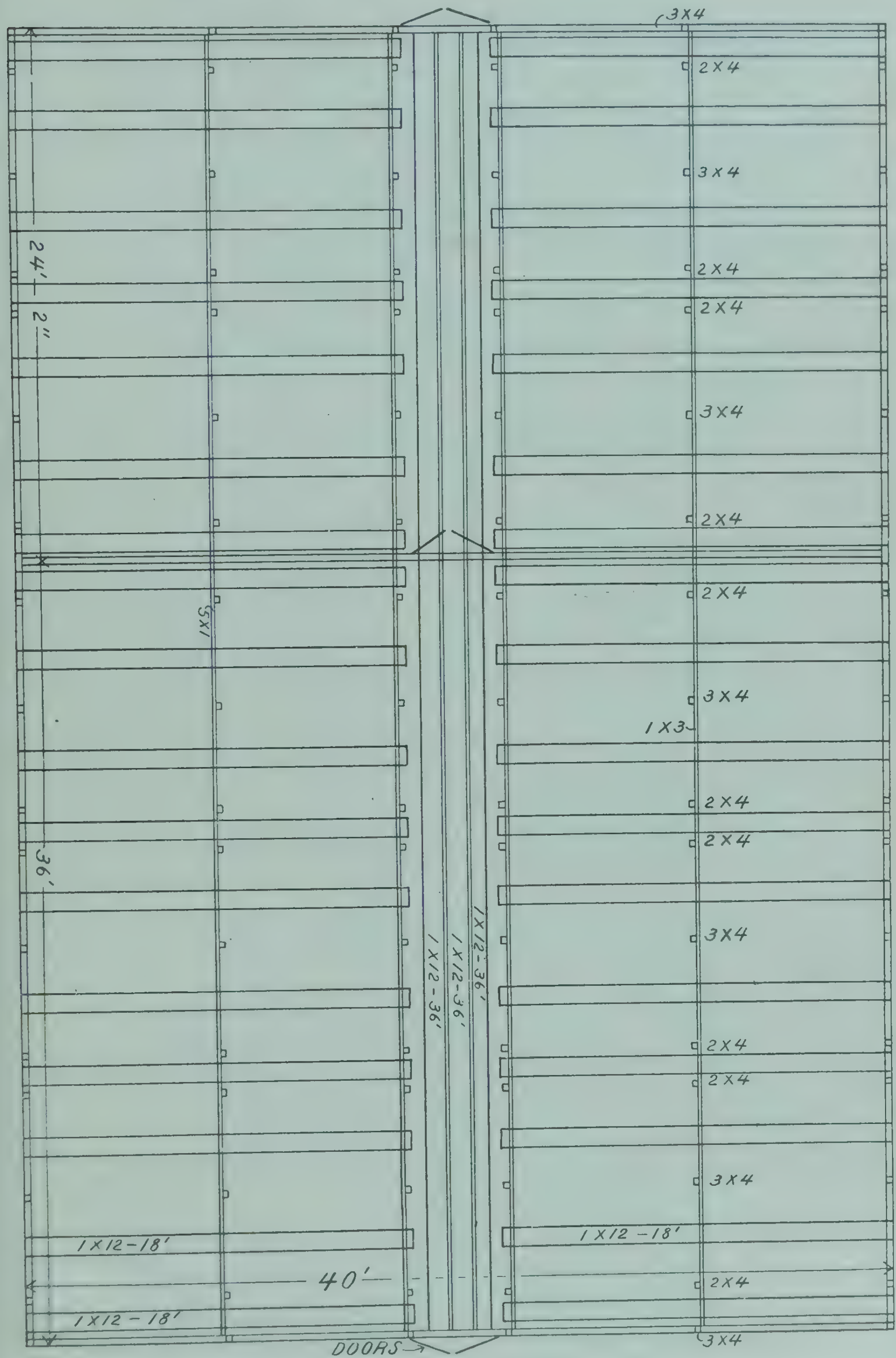

FIG. 4.—Skeleton hanging floors of tobacco barn.

Another necessary building will be a fermenting room, but this can be located at any convenient place on the plantation, the product being taken to it from all the curing barns at the end of the campaign or at a convenient season.

The stringing room should be well lighted and well ventilated, and should be provided with a number of single stalls, arranged with hanging rails, as in the main body of the curing barn.

The fermenting room should be well constructed, with tight floor and tight walls, absolutely under control as to heat, moisture, and ventilation. Near the fermenting room should be a well-lighted and well-ventilated sorting room with large table space, the temperature and moisture under control, in which the tobacco is finally assorted, graded, and classed for baling after the fermentation is completed. A suitable press for baling should be provided in the fermenting room.

These buildings are absolutely necessary if it is desired to produce tobacco of good quality, and they should be provided before the crop is started.

THE SEED BEDS.

The seed beds should be made of 1-inch redwood lumber, 12 feet long, 4 feet wide, and 10 inches deep, provided with gable ends having an angle of 45°. A slot 1 inch by 3 inches should be cut in the apex of each gable end to permit the insertion of a movable ridgepole 1 inch by 3 inches wide and 13 feet long. A strip of muslin 36 inches wide should be fastened by one edge to each side of the ridgepole and a slat about 1 inch by 1½ inches cross section tacked to the lower edge of each piece of muslin. The strips of muslin should be 13 feet long. This constitutes the covering of the seed bed. The advantage of its use is that it can be rolled up when the seed beds are empty, removed to admit sunlight, or either side thrown back over the ridgepole to permit partial exposure in hardening the plants before transplanting.

The soil for the seed beds should be sterilized previous to use. A cheap apparatus for sterilizing soil where live steam is not obtainable is a rectangular box or trough of redwood planks, the bottom of which is made of No. 10 gauge sheet iron. Fasten the iron securely to the bottom of the sides and lead the joints with a mixture of white lead and red lead or steam-fitters' putty. About 4 inches above the sheet-iron bottom of the trough fit in a loose false bottom to sustain the weight of the soil and prevent the dirt falling through to the bottom of the trough. This trough should rest on stone or iron legs about 14 inches from the ground, so that a fire can be built underneath. When ready for use fill the trough with water up to about the level of the false bottom, insert the false bottom, and fill the

trough with the earth which is to be sterilized. Then build a fire underneath and heat until the soil has been thoroughly steamed. The sterilizing process should be continued until the top soil shows a temperature of 200° F.

The soil for the seed beds should be the richest that is obtainable, either leaf mold from the forest or silt from the rich pockets in the gulches, or a compost mixture of grass turf. The richer the soil used in the seed beds the better start the young plants will have before transplanting. It is very important, especially in the cultivation of tobaccos of the finer wrapper types, that the plant should be forced through its entire period of growth, both in and out of the seed bed. The impetus which the young plants get in the seed bed is probably of greater importance than any later efforts to force growth after they have been set in the field. After the tobacco plantation has become established it will pay to prepare each year a compost heap in anticipation of the next year's sowing.

The seed beds should be out of doors. The results of our experiments indicate that seed beds, such as those above described, are much better than either cloth seed houses or open seed beds without cloth cover. If the seed beds are made of redwood their durability will be prolonged from six to ten years, and they should be constructed in such numbers as experience shows to be necessary. There is an advantage in having all the seed beds in one place on account of convenience in watering and caring for them. Enough seed beds should be prepared so that a planting can be made at least once a week during the entire season. This is very important. In fact, it is one of the most important precautions for successful tobacco plantations that there shall be a continuous supply of seedlings at all seasons throughout the year, even though many of the plants are wasted.

Planting the seed consists of scattering it thinly over the surface of the seed beds. Four teaspoonfuls of seed are enough for 40 square yards of seed bed. It is customary to mix the seed with dry wood ashes, which serves the purpose of showing where the seed has been sown. Tobacco seed is so minute that it is almost impossible to scatter it thin enough without a liberal mixture of ashes or some other indicator. The seed of the Cuban varieties is very small, that of the Sumatra varieties a little larger, and that of the seed leaf and other American types larger than either.

Before sowing, the seed should be winnowed to remove all light and immature seed. Only the largest seed should be used. The seed may be winnowed by the use of a bicycle pump or a blast-lamp bellows, attached by a rubber hose to a vertical pipe or tube, open at its upper end. The vertical pipe is about 30 inches high. The tobacco seed is placed in this or is poured into the top while the

blast is in operation. The light seed is blown out and the heavier seed falls to the bottom of the tube.

After the seeds are sown they should be watered, using a watering pot with very fine rose, and the bed will have received enough water when the color of the ashes has disappeared. No covering of soil should be placed over the seed. Germination occurs in from eight to twelve days. The young plants are extremely minute, and the growth is very slow for at least a week. The surface of the seed bed should never be allowed to dry out, but the bed should not be soaked. This will require close attention on the part of whoever attends to the seed beds.

SEED-BED ENEMIES.

The enemies of the tobacco plants in the seed beds are slugs, flea-beetles, and the damping-off fungus. If the seed beds are in the field or open land cutworms are sometimes a serious pest.

Slugs or snails are nocturnal enemies. They destroy the seedlings in all stages of growth. Slugs hide in the daytime under boards or stones, or in the loose earth, near the seed beds. The best remedies against slugs are common salt and lime. If wooden frames are used the paths between the seed beds should be sprinkled with coarse salt.

If sterilized soil is used in the seed beds there will not be much trouble with flea-beetles, but if unsterilized soil is used these are found to be quite destructive. The best remedy is the use of water. Keep the seed bed moist. If allowed to dry out it is not only bad for the young plants, but supplies favorable conditions for the rapid increase in the number of flea-beetles.

Sterilizing the soil will prevent loss from the damping-off fungus, *Rhizoctonia* sp. This fungus is prevalent in Hawaiian soils, especially in the windward districts. It is a parasitic disease of the seedlings of almost all plants. If unsterilized soil is used the only remedy to check the spread of the damping-off fungus, when an outbreak occurs, is to spray the soil with a 3 per cent solution of formalin, or with Bordeaux mixture. A mixture of 3 ounces of flowers of sulphur, 4 ounces of finely powdered copper sulphate, and 14 pounds finely sifted air-slaked lime, thoroughly mixed, dusted over the seed bed with a fine-meshed cloth bag has been found effective as a check against this fungus. If flea-beetles are prevalent add to the mixture 2½ ounces of Paris green.

The remedy for cutworms is poisoning at frequent intervals with a mixture of bran, sugar, and Paris green. This should be scattered over the seed beds in the evening, as cutworms feed almost entirely at night.

Another pest which sometimes causes serious loss is the club root, a disease caused by microscopic worms called nematodes, which bur-

row into and feed upon the living tissues of the roots of the tobacco plant, causing the root to swell up, rot, and decay. In the seed bed there is no known remedy for nematode worms, but cultivation and the drying out that follows thorough aeration, materially decreases their numbers. The only sure method of preventing these pests in the seed beds is to sterilize the soil.

The seedlings should be ready to transplant to the field in from seven to ten weeks from the time the seed is sown. There is no hard and fast time limit. If the season is favorable, and the seed beds are located where the exposure is toward the south, or southwest, with protection from winds, and all conditions are favorable for growth, the plant will be ready to set out in the field within six weeks after germination. If a constant supply of seedlings is maintained by consecutive plantings, the best rule to follow will be that of experience. Select only strong, vigorous, stocky plants, and do not transplant any seedlings which have commenced to shoot up their main stalk. A setback is unavoidable, and seedlings that have begun to make a stalk do not show the same vitality in aftergrowth. The plants should have the advantage of sunshine and full exposure to the air for a week before planting, to harden them off.

FIELD PREPARATION AND TRANSPLANTING.

The tobacco plant is a strong and vigorous grower when once its roots become firmly estabished. Therefore the soil must be in the very best of tilth, because the quality of the tobacco in the field depends on having an abundance of plant food readily available for its use during the entire growing period. The soil should be plowed at least six months before it is ready to plant. Tobacco has a taproot which goes down as deep as the soil is mellow. This taproot is an anchor. The lateral roots are all in the top 6 inches, therefore the fertilizer should not be applied until after the first plowing. The first application of fertilizer should be air-slaked lime, at the rate of 1 barrel (200 pounds) per acre. This need not be cultivated into the soil, as the soluble portion will be carried down through and into the soil by the rains. From three to four months after the first plowing the land should be cross plowed. A dressing of 200 pounds of sulphate of potash and either 400 to 600 pounds of fine-ground raw phosphate (floats or South Carolina rock) or 200 pounds of Thomas slag, should be broadcasted over the field and harrowed in. The second cross plowing should be two or three months before the crop is transplanted. No weeds should be allowed to grow on the land after the first plowing, because these would supply food for cutworms. Clean cultivation is the best remedy for

cutworms. If, however, the weeds have been allowed to grow, the poison-bran mixture recommended above should be broadcasted over the field at least twice within the last month, the last application from three to five days before transplanting. The land should be given a final harrowing within a week before the plants are set in the field.

The first operation of transplanting is to line the field. The lines should be as nearly as possible on contours, so that the wash will be at right angles to the rows across the field. The rows should be 42 inches apart for Cuban and Sumatra, and 48 inches for seed-leaf, manufacturing, or any other domestic tobaccos. At the time of transplanting apply 200 pounds of high-grade fertilizer of approximate composition of phosphoric acid 7, potash 10, and nitrogen 7 per cent; half of the nitrogen in the form of nitrate of soda and half as dried blood or cotton-seed meal. The phosphoric acid should be in soluble form, preferably superphosphate. The potash should not be in chlorid form as chlorin is very detrimental to the burning qualities of tobacco.

The preliminary application of low-grade potash and phosphoric acid would not need to be repeated until several crops had been grown on the same land, but the application of high-grade fertilizer in the row should be applied to every crop.

The tobacco plants should be transplanted on cloudy days or during light rains, or, if no cloudy weather prevails, late in the afternoon. The first cultivations can be done by machinery and horse labor, but after the plant is well established the danger from leaf breakage and disturbance of the surface roots forbids any other cultivation than shallow hoeing. Set the plants level with the surface of the soil and hill up afterwards. Both the Cuban and Sumatra types should be set about 15 inches apart in the row; the seed-leaf, manufacturing, and other domestic types, 24 inches in the row. Replanting should be carried on within thirty days, and every effort made to obtain a full stand. Transplanting can be successfully done with machinery, but replanting must be done by hand. A modern transplanting machine, with a team, driver, and two men, will set and water from 2 to 6 acres of tobacco plants a day. Cultivation should cease within sixty days after the plants are set in the field. The general rule is to discontinue cultivation at topping time. If machinery is not available for setting the plants it will require from 5 to 7 laborers to transplant an acre of tobacco a day. A full stand, at the distance provided for—that is, 42 by 15 inches—will be about 10,000 plants per acre.

TOPPING AND SUCKERING.

The tobacco should be topped after a certain period of growth, which can only be determined by field experience. The nature of the plant being to reproduce itself, a flower bud appears. If left to grow it will branch, flower, and bear eventually a large number of seed pods and innumerable seeds. If the plant is permitted to flower it destroys the value of the leaf. As soon as the flower bud appears and can be removed without injury to the young and tender leaves at its base it must be pinched out with the thumb and finger. The terminal flower bud having been taken out, the plant will produce lateral branches from the axils of the upper leaves. These must be in turn removed without injury to the leaves. This removal of the flower bud creates a diseased or abnormal condition in the plant, and this diseased condition, artificially produced, governs the whole curing and fermentation process after the leaf is harvested. Leaves from plants which have been permitted to flower or produce seeds can neither be properly cured or fermented, and the product from such is woody and worthless. The crop is not tobacco unless the topping and suckering is rigidly carried out. The quality of the tobacco in the market depends in a large measure upon this manipulation in the field.

HARVESTING THE LEAF.

There is no hard and fast rule to indicate when the leaf is ripe. It is largely a matter of judgment to be determined by long practice and experience. The harvesting of the crop requires a great deal of skill, knowledge, and judgment.

The first selection of wrapper, binder, and filler is made on the plant. The wrapper grades, being the highest priced tobacco in the market, demand the greatest skill in selection. Wrapper tobacco should be harvested underripe to preserve the elasticity, and obtain the light colors, which present trade requirements demand. The three grades—wrapper, binder, and filler—should not be harvested at the same time, but each should be taken from the plant separately. Leaves that would have been suitable for wrapper, but which have in any way become broken or injured, should be left on the plant to produce filler. It will not do to harvest broken wrapper leaves and treat them as such. Binder, which consists of the intermediate grade between wrapper and filler, can be allowed to become thicker than the wrapper quality. All other leaves at maturity become filler. None of these grades should be permitted to go past maturity. It is better to harvest underripe than overripe. The harvesting can be carried on in any weather in Hawaii, whether rain or sunshine.

As the leaves are removed from the plant they should be placed in baskets or other light receptacles and taken without delay to the stringing room, where each grade should be kept separate and roughly assorted to length. The fresh leaf should never be piled in deep piles, as it heats very rapidly, and such heating has a tendency to turn the leaf black. It does not harm the leaf to wilt, but it must not be allowed to heat. Having reached the stringing room, and having been roughly assorted to length, from 50 to 60 leaves are strung with a straight needle and cotton thread, back to back and front to front, about an inch apart. The distance between the leaves is readily gauged with the fingers. The string is knotted at one end only. A string of leaves when completed is ready to put on the pole. The tobacco pole is a lath 4½ feet long, ⅝ by 1 inch, sawn out of rough 1 by 12 inch lumber, with a saw scarf at each end cut to a depth of about three-fourths of an inch. When the leaves are strung the knotted end of the string is fastened in the scarf at one end of the pole, the string is pulled tight, passed through the scarf at the other end of the pole, and fastened by weaving in and out. One pound of string is enough for 200 poles. The string should be cut 10 feet 8 inches long, and doubled.

The tobacco is now ready to be placed upon the racks in the curing barn. A barn of the type here recommended should be filled from the bottom upward, so that the green tobacco is always on top, and never below that which is partially cured. The air is essentially humid in the tobacco barn, and it is detrimental to have an ascending current of wet air passing through the tobacco which is partially cured. The poles should be placed at an average distance of about 9 inches apart on the hanging rails, so that the leaves will not touch. It is very important that the leaves should not touch while hanging.

THE CURING PROCESS.

The tobacco crop should be large enough so that a unit of the curing barn can be filled with one grade of tobacco, either wrapper, binder, or filler, in the shortest possible time. This filling of the barn may be allowed to extend from two to three days, but it will be advantageous to fill the unit in a shorter time if possible.

The cure depends upon the exclusion of light, thorough ventilation, and perfect control of temperatures and humidity.

A diseased condition having been produced in the leaf in the field by the topping and suckering process, by which the amount of enzyms in the plant cells are greatly increased, the object of curing is to produce a yellowing in the leaf by prolonging the death of the green cells in the leaf. The yellow color is essential. Without it the leaf cures black. If the leaf dries too rapidly, and yellowing does not occur, it cures green. The whole curing process is a delicate one.

requiring constant vigilance. The control of temperatures, ventilation, and humidity are a matter of practice which will have to be determined in each locality. In general, the temperatures should remain low until the leaf has wilted and should never be allowed to go so high as to set the green color in the leaf. The temperature should exceed humidity from 10° to 15°. If the degree of humidity approaches nearer to that of the temperature, pole rot, stem rot, white vein, molds, and other maladies of the curing barn can not be kept out. In 1906 it is said that 20 per cent of the whole tobacco crop of the United States was affected from these causes. In a humid climate like that of Hawaii artificial heat in the curing barn is absolutely essential for this cause alone, even if its possession did not double the capacity of the curing plant.

As soon as the web of the leaf has passed from the yellow into the brown, the temperature should be greatly increased in order to dry out the stem and veins. The heat does not injure the leaf after the color is once set. As soon as the veins are dry, or as soon as the green coloring has disappeared in them, the leaf is cured and is ready for removal. With artificial heat the curing process may be finished in from twelve to fourteen days. Without heat it will require twenty-four to twenty-eight days. Artificial heat in the curing barn is an insurance and is a very important part of the investment. It insures even color, freedom from disease, and doubles the capacity of the establishment. The tobacco is now ready to take down, assort, and bundle for fermentation. After the unit is emptied it is ready immediately for a new filling. The tobacco will keep in the pile better than it will hanging in the barn on account of danger of molds should a period of wet weather ensue.

SORTING AND BUNDLING.

The tobacco having been taken on the poles to the sorting room, the poles are bunched close in storage stalls of a construction similar to those in the curing barn. Before the leaf is removed from the string it should be roughly sorted into thin, medium, and thick leaves, all damaged leaves being placed with the filler leaves irrespective of thickness. If the tobacco on the pole is mainly thin leaves, the medium and thick or broken leaves should be stripped from the string, and vice versa, care being taken not to tear or break the leaf in pulling it off the pole. The thin, medium, and thick leaves should be placed in separate compartments. The pole having been culled, the string is taken off the pole and the leaves drawn off from it. As rapidly as assorted, the different grades should be bundled into hands. A hand consists of from 50 to 100 or more leaves. The stems are gathered in the palm of the hand between the thumb and

forefinger, all butts being kept even. When the hand is from 2 to 3 inches in diameter, it is tied by bringing one leaf up over and twisting it around the butts, the loose end being tucked into the hand. As soon as from 1,000 to 1,500 pounds of tobacco of any one grade has been assorted, it is ready to ferment.

When taken from the curing-barn to the sorting room, the tobacco should be moist. If the weather is cloudy or rainy, no artificial additional moisture will be necessary, but in a dry period, or when the humidity is low, the tobacco can be moistened by wetting down the walls and floor of the sorting room, or by turning live steam in the room, in case a steam plant has been provided. The tobacco must never be sprayed or any direct application of water made to it. A properly cured leaf absorbs moisture from the air with great rapidity and will hold from 20 to 25 per cent of moisture without detriment. This is about the amount it should contain when placed in the fermenting heap.

FERMENTING.

The fermentation should follow immediately after the grading and sorting process, as the tobacco is then in the best condition. A much better fermentation can be secured immediately than after a delay of weeks or months. The tobacco is taken from the assorting room to the fermenting room. The fermenting room is provided with platforms 5 feet wide and of sufficient length to hold from 1,000 to 1,500 pounds. These platforms are raised a foot above the floor and should have a bulkhead at each end, about 5 feet high. The platforms are covered with cotton cloth, burlaps, or some other cheap material to keep the tobacco from coming in contact with the lumber of which the platforms are constructed. To build up a bulk or fermenting heap the hands are laid close in 4 or 5 rows until the bottom is completely covered, the butts overlapping the tops about a third of the length of the leaf, and subsequent tiers are added until the quantity at hand is all in the pile. A tin or copper pipe, about 2 inches in diameter, closed at one end, should be stood in the center of the pile and the tobacco built up around it. This tube should be long enough to reach above the top of the pile of tobacco, and the open end is placed up. This pipe is to be used for a thermometer, which can be lowered to a position corresponding with the bottom, middle, or top of the pile. If the tobacco is in proper case when it is placed in the pile—that is, if the leaf contains 20 to 25 per cent of moisture—a rise in temperature will begin at once. The fermenting heap when finished should be covered over with a tarpaulin or rubber blanket, excluding all air and retaining all moisture. No weight should be applied. When the building of the fermenting heap is finished the temperature of the room should be raised

from 8° to 10° above the temperature of the pile until the temperature of the pile becomes equal to that of the room. In the tobacco districts of Hawaii the summer air temperatures are about 65° to 75° inside the buildings. The fermenting room should be heated to from 85° to 95° and should be kept at that temperature until the temperature of the pile of fermenting tobacco equals the temperature of the room. As the temperature in the fermenting pile of tobacco increases above 90°, the air temperature should be permitted to remain about 10° lower than the increasing temperature of the pile.

Wrapper, binder, and filler tobaccos require different treatment in fermenting, the best wrapper tobaccos being produced at lower temperatures than fillers. The higher the temperatures in the fermenting pile the darker the color of the finished leaf. Under no circumstances must the temperature of the fermenting tobacco be permitted to rise above 136° F. As soon as the temperature in the middle of the pile, which is the hottest, reaches 100° F., the pile should be torn down and rearranged on an adjoining platform. The bottoms, sides, and tops are placed in the center of the new pile, and the center of the first pile becomes the outsides, bottoms, and tops of the second pile. This process should be continued throughout the various rebulkings.

Indications are that the best qualities of wrapper leaf should not be allowed to go much over 100° F. If light colors are shown—that is, if the color of the leaf is desirable—fermentation may be reduced to a minimum, which will mean that the pile will have to be rebulked perhaps every twenty-four hours. An important point is to maintain a constant degree of humidity in the fermenting room. The air in the fermenting room should never be permitted to become dry, but should always show from 85° to 90° of humidity, irrespective of the temperature. In wrapper tobacco color is everything. As the piles are broken down and rebulked there is each time a slower rise in temperature, and it is a matter of judgment as to when the fermenting process should be discontinued. When the stage is reached where the temperature of the tobacco in the pile rises, remains stationary, and then begins to fall, the fermentation is finished.

Binder tobacco will stand more fermentation than wrapper. Thick wrapper will stand more fermentation than medium wrapper, and both than the thinnest or highest quality of leaf. The better the quality of the tobacco the greater care should be exerciesd in its manipulation. In the case of filler tobacco it is best to allow the temperature to approach the maximum limit of 136° at the second turning, the subsequent rebulkings being checked at lower temperatures. In the first stages of fermentation large quantities of ammonia are set free,

the necessary equipment has been prepared, the field operations may be begun. To do things the other way round is to risk the whole investment, for tobacco is not tobacco unless it is properly handled. The best Partidos, Cuban wrappers, and the plants producing Deli or other famous Sumatra types, are forced from the time the young plant makes its appearance in the seed bed. On the best Cuban plantations the plants are watered in the field every three or four days during the whole growing period. That plant which grows the most rapidly, other things being equal, will produce the best leaf, and of two plants set side by side, the one forced and the other not, that which is forced will produce the greatest percentage of wrapper leaves on the plant.

To grade the leaf and cure it requires a heavy investment of capital, but the growing of the leaf alone is an ideal occupation for a farmer of small means. It is becoming customary in Florida and other tobacco-producing sections of the United States for the larger growers, who control the curing barns and operate the fermenting and assorting establishments, to purchase the green leaves from small producers. The value of the finished product is sufficient to enable the larger tobacco grower to cultivate his small neighbor by paying good prices for the leaf. In fact, it is to their interests to do so. The greater the acreage of tobacco planted in any section, the greater will be the stock from which to select grades of the highest quality.

It is, furthermore, an advantage—even more than that, a necessity—that every tobacco-producing section should have a large permanent population from which to draw labor, and the individuals of that community should be landowners. The crop calls for a great deal of labor, and when labor is required it can not be put off. Wrapper tobacco which is allowed to become overripe will not make good wrappers and is not salable as such. Sumatra wrapper tobacco of the best lengths and light colors cost $4 per pound laid down in New York in April, 1907, whereas prime domestic filler was obtainable at from 15 to 20 cents per pound. This relative proportion between filler and wrapper almost always prevails, so that every effort must be made to force the tobacco plant to make wrapper leaves, and to so cultivate, cure, and ferment that the largest proportion of wrapper shall be of suitable colors, sizes, and texture. The rewards of the successful cultivator are greater than in almost any other agricultural crop.

On account of the fact that the enemies of the cultivated crop increase rapidly with each successive cultivation on the same land, it is highly desirable that the land should be occasionally allowed to rest. Hence, to grow an annual crop of 100 acres of tobacco the planter should own or have available, if required, from 250 to 350 acres.

FIG. 1.—CUBAN VUELTA ABAJO.
Leaves 16 to 30 inches long.

FIG. 2.—CUBAN FILLER.
Plant produced ¼ pound cured tobacco.

FIG. 3.—MANILA TOBACCO.
Leaves 12 to 26 inches long.

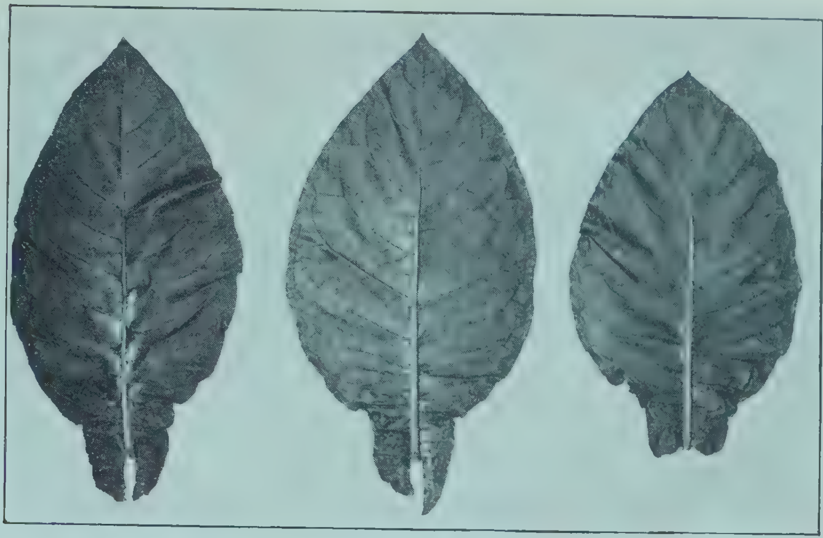

FIG. 1.—CUBAN TOBACCO.

FIG. 2.—SUMATRA TOBACCO.

FIG. 3.—SUMATRA TOBACCO, BELGIAN TYPE.

YIELDS.

The yield of tobacco varies according to the variety, the season, the time of planting, and the quality or grade of the type which comprises the majority of the crop. Cuban filler tobaccos (Pl. II, fig. 2)—that is, plants grown from the seeds brought directly over from Cuba—yield from 600 to 1,200 pounds of leaf. Sumatra tobaccos (Pl. III, figs. 2 and 3), brought directly over from Sumatra, will yield from 900 to 1,200 pounds. Cuban tobacco which has been grown two or three years, or more, in Hawaii yields from 900 to 1,400 pounds, while the second, third, and succeeding generations of Sumatra type grown in Hawaii yield from 1,200 to 2,000 pounds. All of these types show improvement in quality when grown under Hawaiian conditions. The results of three years' experimental work with tobacco in Hamakua show a remarkable increase in the percentage of wrapper leaves the third year over that produced by plants grown from seed imported direct from either Cuba or Sumatra. With full stands and favorable seasons, it is believed that 30 per cent of either the Cuban or Sumatra tobacco (Pl. III) will produce high grade wrappers, and this percentage can be materially increased. While there is a wide variation in prices for the different grades of tobacco, this crop differs from most others in that not a single ounce is produced that is not salable, provided they are carefully separated from the better grades. It is believed that for many reasons it will not be profitable to cure tobacco and sell the crop in bulk without sorting or fermenting, as is the custom in most of the mainland districts. Hawaiian tobacco is a tropical tobacco, and direct competition will come with countries in which the last assortment is made on the plantation where the crop is grown. By adopting this system only the best grades should be shipped to the best markets, and the seconds manufactured at home.

SOILS AND CLIMATE.

The characteristics of the tobacco soil were discussed in a previous publication of this station.[a] It is only necessary to recapitulate by saying that the tobacco soil should be light, porous, well drained, with a large percentage of humus. This characterization fits almost all Hawaiian soils, and it is our opinion that tobacco can be grown practically all over the group.

With tobacco, as with all other plants, sunshine tends to thicken the leaf and contract its size, while shade or partial shade tends to produce a larger leaf of great thinness. Tobacco-growing regions where the sunshine is excessive produce only filler tobacco. The

[a] Hawaiian Sta. Press Bul. 12.

flavor of such leaf is usually better, stronger, and more pronounced than that of tobacco grown in the shade. Flavor and aroma are not considered essential qualities of wrapper tobacco, thinness, elasticity, and burning qualities overweighing them.

The burn of Hawaiian tobacco is exceptionally good, irrespective of whether it is grown in the windward or leeward districts. Burning qualities of the leaf are dependent upon the texture of the soil, its percentage of clay, and its water-holding capacity. The color of the leaf depends upon the time of harvesting and the manipulation in the curing barn. Elasticity is governed in some measure by the period of maturity at which the leaf is harvested. The texture of the leaf—that is, whether it is thin or thick—is governed by the amount of sunshine and the rapidity of growth. The flavor is largely a matter of sunlight. The aroma depends upon the gumminess of the leaf.

In Hawaii the best tobacco districts are in the cloud belts on the slopes of the higher mountains, provided always the rainfall is sufficient. Tobacco of good quality can be grown in the Hamakua, Hilo, Olaa, Puna, Kau, and Kona districts on the island of Hawaii; in Kula, Makawao, and Koolau districts on Maui, and in similar areas on the islands of Lanai, Molokai, Oahu, and Kauai. The best districts are undoubtedly on the larger island. The windward cloud belts there supply a larger rainfall than in the Kau and Kona districts, and will undoubtedly become the best sections for the cultivation of this crop.

It is a popular impression that tobacco will not stand wind, but this is undoubtedly an error. The plant has a very strong tap root, so that it is never blown over, and the leaves do not ordinarily whip or break as would be supposed in the case of so large a leaf. The growing tobacco leaf is pliable and not easily injured.

Hawaii differs in climatic conditions from both Cuba and Sumatra. In Cuba tobacco is grown as a winter crop, being planted from October to December, and harvested in the drier months—from February to April. Tobacco is practically never grown in Cuba during the summer months, which in that part of the world is the season of excessive rains. In Sumatra there are distinct dry and wet seasons. The tobacco is planted at about the end of the wet season, so that it will come to maturity in the early part of the dry season. The Sumatra planting season is from March to May, and the harvesting season from July to September. In Hawaii there is no pronounced wet or dry season, at least not in the windward districts of the islands. This is an advantage in that planting can be made almost continuously throughout the year. Experience indicates that the spring and autumn plantings should be made of the Cuban and the midsummer crops of the Sumatra types. The Cuban will

tand more cold than the Sumatra and is in every way a hardier dant. The rainfall is somewhat higher in Hamakua than it is in he best tobacco districts in Sumatra, but the humidity is higher, and he temperature is lower. It is believed that the uniformity of temerature is advantageous to the production of the highest quality of obacco, while detrimental to some extent in curing. This can be vercome by artificial means. The factor which is of the greatest nportance is undoubtedly that of the prevailing cloudiness. There vill be no necessity for artificially shading tobacco in any of our egions of daily cloud accumulation.

PROBLEMS OF TOBACCO CULTURE.

As has been recently pointed out by other investigators, there is large field for work in the selection and breeding of improved ypes of tobacco. The crop from almost any lot of seed from whatever source shows the widest possible variation in size, vigor, shape, nd quality of plants. Considerable work along this line has already been done, and our results are such that we should advise every obacco raiser himself to select and breed those types which most ompletely fulfill the commercial requirements. In working through he fields any plant that shows desirable characteristics should be eserved for seed purposes and protected from cross-fertilization. The leaves should never be cut from a plant that is to be allowed to go to seed.

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1055 Issued July 3, 1908.

Reg. B. 1. P.

HAWAII AGRICULTURAL EXPERIMENT STATION.

J. G. SMITH, SPECIAL AGENT IN CHARGE.

BULLETIN No. 16.

THE CEARA RUBBER TREE IN HAWAII.

BY

JARED G. SMITH,

SPECIAL AGENT IN CHARGE OF HAWAII AGRICULTURAL EXPERIMENT STATION,

AND

Q. Q. BRADFORD,

ASSISTANT IN RUBBER INVESTIGATIONS.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *March 10, 1908.*

SIR: I have the honor to transmit herewith, and recommend for publication as Bulletin No. 16 of this station, a paper on the Ceara Rubber Tree in Hawaii, prepared by myself, assisted by Mr. Q. Q. Bradford. The paper embodies the results of one year's experiments in tapping rubber trees. It is believed that the methods and apparatus devised represent a distinct advance toward the successful solution of the problem of commercial tapping of trees of this variety for the production of rubber.

Respectfully,

JARED G. SMITH,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.

A. C. TRUE,
Director.

Publication authorized.

JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

THE CEARA RUBBER TREE IN HAWAII.

INTRODUCTION.

The natural home of the Ceara rubber tree (*Manihot glaziovii*) is in the dry regions of Brazil. In former years it was very abundant in the State of Ceara and derives its name from this fact. It is also known as the Manicoba rubber, this having been its native name.

BOTANICAL RELATIONSHIPS.

This tree is closely related to the cassava (*Manihot utilissima*). It belongs to the spurge family, which also includes the Para rubber (*Hevea brasiliensis*) and many other rubber-producing plants. Most of the members of this group, the Euphorbiaceæ, have milky sap.

HABIT OF GROWTH.

The Ceara rubber is a rapidly growing tree with a loose, spreading, and not very leafy top. It usually branches in threes and these again branch in turn, and so on during the life of the tree. The leaves are long-petioled, simple, peltate, deeply three to seven palmately parted, the uppermost leaves entire; the lobes are entire, broad, ovate-lance-shaped. When growing in the open, under favorable conditions, the trunks of the Koloa grove of trees, 14 years old, average about 44 inches in circumference at 3 feet from the ground. In a natural forest the trees begin to branch from near the ground to 20 feet or more above. The wood is soft and spongy, and the growth rings are not prominent.

THE ROOT SYSTEM.

The roots (Pl. I) are shallow and are not very numerous. They are thick and fleshy and bear elongated, fleshy tubers, very much resembling the roots of the cassava and sweet potato. The young tubers have a very thin bark and contain a large percentage of starch. As the tubers grow older the bark thickens, the outer surface becomes woody, and the center is filled with pith, saturated with water.

THE LATEX SYSTEM.

The latex occurs in the leaves and leaf petioles and in the bark of the twigs, trunk, and roots. The wood contains no latex, although there are latex tubes in the pith. There is a continuous network of milk tubes all through the living, green portion of the bark of the trees.

The innermost portion of the bark of all dicotyledonous trees is the portion from which growth proceeds, and is called the "cambium" layer. On the inner side of the cambium wood cells are produced, but growth outward produces the tissues known as bark. Growth in diameter is by accretion of wood in a continuous layer around the whole circumference of the trunk on the inner side of the cambium. There are no milk tubes in the cambium. The cambium being the most vital portion of the tree, the greatest care must always be exercised to prevent cutting too deep and injuring this layer of tissues.

The latex, or milky sap, of the rubber tree is of very complex composition, containing starch, sugars, gums, resins, proteids, and salts, as well as rubber. The milk tubes are not continuous—that is, it is not possible by cutting through the network of tubes at the base of the tree to drain out all of the latex. The latex-bearing tissues may rather be compared to a series of short tubes joined end to end with permeable diaphragms between. In the living plant there is free transfer of latex from one tube to another, but there is no circulation comparable with the circulation of the blood in animals. There is no rise and fall of the sap, as is the common belief, and so far as has been determined, there is no ruling direction of movement at any time of the day or period during the growth of the plant. The circulation of the sap in the tree or of latex in the milk tubes is simply a process of life, a phenomenon of growth.

The rubber in the latex in the milk tubes is supposed to exist as an emulsion, somewhat comparable to fat globules in milk. When a milk tube is ruptured, to permit its contents to escape, the rubber globules rapidly agglutinate, the function of rubber apparently being to close up wounds and prevent the loss of water from the tree by evaporation.

The flow of latex when the milk tube is ruptured is not due to the continuity of the tubes, as would be supposed, but is because the latex is under tension in the growing trees. When the pressure is relieved by the breaking or cutting through of the tissues containing the latex, the tension being released, the milk tubes for a short radius around the wounds quickly empty themselves of their contents.

TUBEROUS ROOTS OF A SIX-MONTHS-OLD CEARA RUBBER TREE.

THE SEED.

One of the characteristics of the Ceara rubber tree is that it sheds its leaves in the spring of the year. After a rest of from one week to two months new leaves are put forth and growth is renewed. The flowers are produced in the early part of the summer. These are greenish yellow, with a very abundant supply of nectar. The seeds are borne three together in a round capsule about an inch in diameter. When the seeds ripen the capsule (Pl. II, fig. 2) dries and explodes, throwing the seeds often 10 or 15 yards from the mother tree. The seed is shaped somewhat like a plum pit, about 0.5 inch long, mottled grayish brown, smooth, and shiny. The seed coats are hard and stony. The seed retains its vitality for two or three years or more, and is apparently more readily germinated when at least six months old than when fresh from the tree.

THE SEED BED.

Considerable care is needed in the selection and preparation of the ground for a nursery. It should be placed in a warm, sunny location, well protected from the winds, and, in the drier portions of the islands, with a near-by water supply. Two methods of starting the seeds are in vogue. Either sow the seed in nursery rows in the ground or plant them in flats, or shallow boxes filled with loose, mellow earth. The same care is necessary in selecting the earth for either seed boxes or nursery plantings as in the case of any other forest tree seedlings. An arrangement of partial shade, either by coverings of slats or cloth, is highly desirable.

SEED-BED ENEMIES.

The most serious enemies of seedlings, apparently rather common in Hawaiian soils, are the nematode worms. It has been found that the very large losses of seed in the seed beds have been due in many instances to the ravages of this microscopic worm instead of to the lack of vitality of the seeds.

There is no known cultural remedy for nematode worms where they affect cultivated crops. In a nursery, however, where the amount of soil used is comparatively small, it is entirely practicable to prevent infection by sterilizing the soil, as is recommended for the tobacco seed bed.[a] This is best accomplished by the use of live steam. The soil should be cooked for an hour or more—long enough to kill all larvæ, eggs, and adults not only of nematodes but of all injurious insects in the soil. Sterilization of the soils used in nur-

[a] Hawaii Sta. Bul. 15.

series will also prevent, in a large measure, losses from the damping off fungus, molds, and other fungi.

PREPARATION OF THE SEED.

The natural germination of the Ceara rubber seed requires about a year because of the very thick, hard, waterproof seed coats (Pl. II, fig. 1). To hasten germination various methods of treatment are employed. Probably the best of these is to file the edges. The best place to file the seed is where it is flattened at the base, directly over the plumule. Care should be taken not to file too deeply so as to injure the plumule. Another method is to pour boiling water on the seeds and allow them to soak for twenty-four hours. Another is to soak the seeds in water and then germinate in the bottom of a "sun box," a shallow box painted black on the inside and covered over with a sheet of glass. Still another method is to place the seeds in shallow soil over hotbeds filled with fresh stable manure. This method is undesirable because of the liability to infection from molds and the damping-off fungus often present in fresh manure.

Seeds from 6 to 18 months old usually germinate better than seeds fresh from the tree. Heavy losses in the seed beds occur through the depredations of rats and mice, which are very fond of these seeds. Ants, too, are very injurious. Rats may be poisoned or trapped, or the seed beds may be protected from their incursions. The best method of getting rid of ants is to put the seed boxes on posts protected with ant poison. It is also well to destroy the ant nests with boiling water or carbon bisulphid.

TRANSPLANTING TO POTS.

A week after the seeds have germinated the young plants should be transplanted into pots. A convenient form of pot for transplanting rubber seedlings or, for that matter, any other tree seedlings is one made of ti leaves formed over the bottom of a quart bottle and tied with string or fiber, taking two leaves to make the pot. Pots may be cheaply made of heavy manila paper dipped in hot paraffin, paper alone being too easily torn when wet. A joint of bamboo filled with earth makes an excellent pot. Using either of these styles, the plant is set out in the field in the pot at the time of transplanting, and there is no marked retardation of growth, as often follows when the plants are dug from nursery rows.

TRANSPLANTING TO THE FIELD.

Before the seedlings are taken to the field the ground must be prepared for them. In the Nahiku and other wet districts the land is first cleared of standing timber and underbrush and the fern stumps

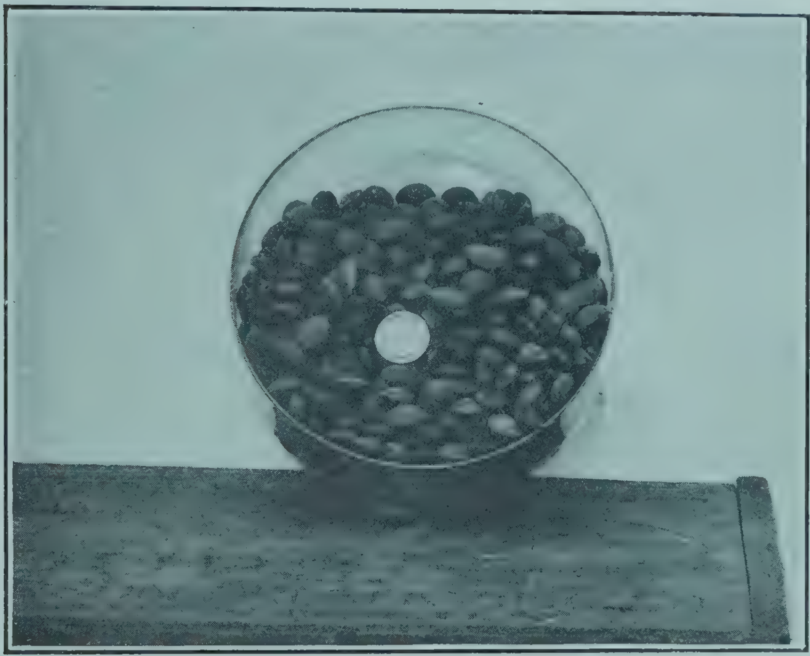

FIG. 1.—CEARA RUBBER SEED.

FIG. 2.—SEED CAPSULES OF THE CEARA RUBBER TREE.

are cut and piled. In the drier locations in Kona, Puna, or Koloa, in Kauai, or any other leeward districts of the islands, the lantana and guava are cleared and burned and, if free from rock, the land should be plowed. Plowing, however, is not practicable in many of the districts where the cultivation of rubber has been undertaken. Where the land can not be plowed holes are dug at proper distances. The holes should be at least 2 feet across and as deep as practicable. If the soil is porous the hole or circle of cleared ground in which the tree is to be planted can be most cheaply prepared with a hoe or mattock. In the heavier soils a good method is to blast, using giant powder. A $1\frac{1}{4}$-inch octagon steel, sharp-pointed drill is driven down about 2 feet and one-third of a stick of No. 2 giant powder with fuse cut just long enough to reach above the surface, is dropped into the hole; no tamping is required. Blasting is cheaper than digging where the soil is close and dense, and this method has the further advantage that the land can be very quickly prepared, two men making from 150 to 225 holes a day. When blasted, the land is left in better condition than where a hole is dug with pick and shovel, as the subsoil is opened up and cracked, allowing the roots to penetrate. This method also improves the drainage.

WHEN TO TRANSPLANT.

The best time to plant the Ceara rubber tree is in the spring, from January until March, following the rule which applies to all agricultural crops, that those seedlings which receive the benefit of hot, growing weather make a better and more healthy growth than those planted at the end of the growing season. If in pots, these should be watered before transplanting. A good time to transplant is in the evening or late afternoon, or on cloudy days, so that the plant may become accustomed to its new location without excessive wilting. Even if the seedling is in a ti leaf or paper pot there is more or less disturbance of its roots when transplanted.

DISTANCES FOR PLANTING.

There is considerable variation in the distances of planting adopted on rubber plantations. One method is to plant in a double row, 5 by 15 feet. Other plantings range from 10 by 10 feet to 20 by 20 feet. The object of planting close would be to have the plants more quickly shade the ground and economize on cultivation, through the shading of weed growth. However, as the tree will not reach a sufficient height to shade the ground short of three years, other things should be considered. The proper distance of planting will have to be worked out in each of the districts of the islands, and will depend as much upon the ability of the soil to grow the trees

as on the habit of growth of the tree itself. Another advantage of close planting is that in three to five years, when tapping begins, trees of poor growth or individuals poor in rubber, or those that are diseased or unhealthy, can be cut out and destroyed, and there will still be enough left for plantation purposes.

CULTIVATION.

The rubber planters in Hawaii have thus far confined themselves to the growing of rubber as the sole agricultural crop. It is a question whether this is the best policy on account of the time required for the trees to attain the proper size for tapping and because of the expense of maintenance through these early unproductive years. It is believed that better results can be obtained through growing some annual or biennial crop to yield an immediate revenue. The advantages would be cultivation of the trees as a secondary crop only, saving expenses, and obtaining a better and more rapid growth of the rubber trees through the cultivation of the land between them.

The cultivation of plantations already in existence in Hawaii has in the main been limited to clearing the weeds from a circle around the trees. In some instances where the growth is excessive the weeds have been mowed and used as a mulch around the base of the trees. The mulching of rubber trees is highly recommended for the Kona districts, especially if the mulch is covered with earth. On only one plantation has there been any attempt to adopt clean cultivation. It is believed that pineapples, tobacco, soja beans, bananas, cassava, cotton, and garden vegetables are crops which may be profitably grown in rubber plantations. Any one of these will yield returns more quickly than rubber, and all are on a basis of profitable cultivation. Such catch crops can be cultivated for two or three years, not only without detriment to the roots of the rubber trees, but to the very decided advantage of this final crop, through the loosening up and stirring of the soil.

FERTILIZERS AND CATCH CROPS.

If catch crops are grown in a rubber plantation the commercial fertilizers used should be of low grade, containing little more than enough nitrogen to satisfy the needs of the catch crop, and potash and phosphoric acid in such forms as will become gradually available during the period of several years after the catch crop is disposed of.

While this station has undertaken a number of pot experiments to determine the value of fertilizers as applied to rubber, only an indication of the fertilizer requirements has thus far been obtained. The Nahiku soils require lime and potash. The lime should be applied at a rate of not over 200 pounds per acre. The potash should

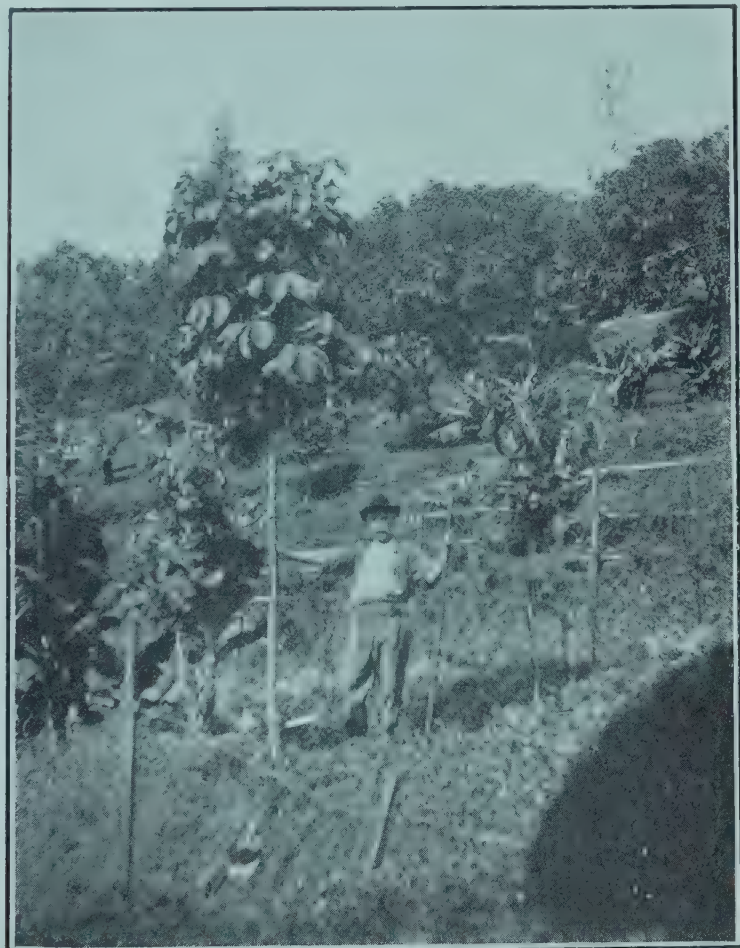

Fig. 1.—Sucker Nine Months Old, the Marks (+, —) Showing Point, Near the Ground, at which the Tree was Cut Off.

Fig. 2.—The Top Cut From the Root of the Tree Shown in Fig. 1, Planted as a Cutting, Thirteen Months' Growth.

Two Rubber Trees from One Seed.

be in the form of either sulphate or of double magnesium salt, and should be applied immediately around the tree.

While rubber cultivation is a new industry in Hawaii and conclusive work has not as yet been done, the probabilities are that the highest yield of rubber per tree or per acre will be obtained from trees which have made the most rapid and vigorous growth, and every effort should be made to promote this end. The Ceara rubber is a plant new to cultivation, but it is probably safe to say that it will respond as readily to scientific methods as have other wild plants.

PRUNING.

Very little work has been done with pruning rubber trees in Hawaii. Enough, however, is known to indicate that it is advisable to force the tree to produce a straight, unbranched trunk not more than 10 feet in height. If the tree shows a tendency to grow 15 to 20 feet without branching it should be forced to branch at from 7 to 10 feet from the ground by cutting off the terminal buds of the main trunk, and again cutting back the main shoots as they appear, until two or more branches are formed. Trees that branch near the ground, or under 7 to 10 feet in height, should have all but one of the branches pruned off, and this operation should be repeated if the tree shows any tendency to again branch below that height. The pruning should be done just as soon as the branches are put forth. If the branch is allowed to become large before being cut off, the tree will make a crooked trunk, which will be difficult to tap later on.

PROPAGATION BY CUTTINGS.

The Ceara rubber tree is very readily propagated by cuttings. The best cuttings are taken from young trees, as they are not so likely to branch (Pl. III). Cuttings taken from eight to ten year old trees, especially trunks or branches of considerable diameter, show a great tendency toward branching at once. Even limbs that are broken from the tree or trees that have been overturned by storms will grow if cut in 2 or 3 foot sections and placed in the ground for about two-thirds of their length. A number of instances are on record where Ceara trees used for fence posts have taken root and continued growth. Seedlings six months or a year old may be cut near the ground, the trunk cut in two or more pieces, and set out in the field. These will root and throw up new suckers, which often make larger and better trees than the original.

ROGUING THE PLANTATION.

No two rubber trees are alike. For this reason every tree in the plantation should be tested before it is two years old to determine whether it yields a paying quantity of latex. There is no need of

waiting four or five years to cut out unproductive trees. The widest variation exists both in the proportion of rubber contained in the latex and in the amount and freedom of flow of the latex itself. The outward appearance of the tree is no indication of its value as a rubber producer. The latex of some trees is thin and watery. The older the tree the thicker the latex, but there is great difference even among young trees. Trees yielding thin, watery latex without any appreciable amount of rubber should be cut out and destroyed and their places filled with cuttings taken from trees yielding large quantities of rubber. The value of the plantation can be rapidly increased by vigorously pursuing this policy.

SYSTEMS OF TAPPING.

A striking characteristic of the Ceara rubber tree is that it sheds its bark at frequent intervals. The outer bark is tough and papery. As new growth of bark forms immediately outside of the cambium layer, the outer bark dries and sloughs off. This process is continuous.

Before beginning tapping the entire outer bark should be removed from the trunk without injuring the living inner bark. This is easily done with a curved-blade knife shaped like a pruning hook, making one vertical cut and peeling off the bark in rings.

There are four systems generally employed in tapping the Ceara and other rubber trees in rubber-producing countries. These are the half herringbone, the full herringbone, the spiral, and the vertical cut systems. The half herringbone consists of a single vertical cut with laterals about a foot apart at an oblique angle extending half around the tree. The full herringbone consists of a vertical cut with oblique laterals on both sides extending entirely around the trunk of the tree. The spiral is a single or double oblique cut extending from the bottom to the top of the tapping area without vertical channels. In the vertical system there are from one to half a dozen vertical cuts without oblique laterals.

The Ceara rubber tree differs from both the Castilloa and Hevea in the rapidity of the coagulation of the latex. For this reason it has been found that the system of vertical cuts is the best. The station has carried on a large number of experiments in methods of tapping. It has been found that the average Ceara tree stops its flow of latex by complete coagulation within from two to five minutes when the latex is permitted to flow in the wound without the use of water. By trickling water over the wound the period of flow may be extended several minutes, but if the water is rendered alkaline with ammonia the period of flow is extended sometimes from thirty to forty minutes.

It has also been quite definitely determined that a system of single or double vertical cuts, from 3 to 6 inches apart, without any oblique laterals except at the base, for the purpose of concentration of all the latex at one point, gives the heaviest yield of rubber and the least waste. A vertical cut is much more easily made than either the spiral, half herringbone, or full herringbone oblique cuts. Another point in favor of the vertical cut is that the wound thus formed heals with the greatest rapidity.

The first cut should be extremely shallow. The cut should be flat, with sharp sides one-eighth of an inch wide and, if practicable, not more than one thirty-second of an inch in depth—the thinnest possible shaving. It is especially important in young trees not to cut too deeply, because the bark is very thin and there is great danger of permanently injuring the tree by cutting through to the cambium. The second tapping should be in the same cut without widening it. The next cut and the cuts of each succeeding day, as long as the tapping period lasts, should be to simply freshen the wound at one side only of the vertical incision. In this way the tapped area will be extended gradually in one direction around the trunk and will be followed by rapid healing of the wound from the opposite margin of the cut. The number of vertical cuts will depend on the diameter of the trunk. They should be not less than 4 or 5 inches apart, because the daily tappings drain the latex from the bark for from 1 to 2 inches in every direction from the wound. Enough uninjured bark must be left between the wounds to admit of rapid recovery and not too seriously interfere with the vital processes of growth.

TIME TO TAP.

The best time to tap Ceara rubber trees is at night or during the early morning. If tapping is done during the day it should be on the shady side of the tree. The reason for this is because of the tension of sap and latex in the body of the tree. Evaporation of water from the leaves is most rapid during the daytime. The greatest activity in pumping up water from the soil is also in the day. Under the action of direct sunlight the leaves accumulate great quantities of starch and sugars. At night there is a transfer of carbohydrates in soluble form from the leaves to those parts of the tree where growth and the formation of new tissues are taking place. During the hours of darkness there is an almost complete cessation of evaporation from the leaves, but the roots continue to take up water from the soil. This results in tension and explains the reason why the flow of latex is very much heavier and more rapid during the night. Coagulation is also retarded by the lower temperatures at night.

The best time to tap seems to be between 12 o'clock midnight and 7 o'clock in the morning. It is believed that some adaptation of the

miner's lamp to be worn on the hats of the workmen will be necessary. If the tapping operation is postponed until earliest dawn it would largely increase the number of men required, owing to the few hours during which profitable tapping can be carried on.

The best season of the year for tapping has not been determined, but the indications are that it would be during the rainy season. In Hawaii the Ceara rubber trees can be tapped at any time of the year, but this operation should not be carried on during the resting period when the tree is bare.

APPARATUS AND METHOD OF TAPPING.

As a result of many trials, it was found that a cloth or canvas water bag was of great advantage in collecting the rubber (Pl. IV). A water bag large enough to hold about a quart of water, made with alternating narrow strips of thin porous cloth and oiled cloth or canvas, as shown (Pl. IV, fig. 2), is tied around the tree 6 or 7 feet above the ground, just above the tapping area. These bags are of cheap construction and will last for many months if properly cared for. A water bag should be fastened to each tree before tapping begins and should be left on the tree during the whole tapping season.

At the base of the tree the water and latex are collected in zinc, galvanized-iron, copper, aluminum, or enameled cups, or in wooden or earthen vessels. Iron vessels should not be used because of the corrosive action of the ammonia recommended for use in tapping. The water and latex are collected at one point at the base of the trunk by inserting a thin sheet of zinc obliquely beneath the outer bark. The channel and spout thus formed should not be fastened into the body of the tree because of injury to the wood. This tin or zinc collar and spout should be left on the tree during the whole tapping season.

The knife used should cut a shallow, flat channel with vertical margins and should be capable of delicate adjustment, because the bark of the Ceara rubber tree is very thin.

The preliminaries having been attended to, a water carrier goes through the grove, filling each of the bags with a pint of water containing ammonia at the rate of one-half ounce per gallon of water. The rubber contained in the latex of young trees coagulates more slowly than in old, so that in tapping a young grove a minimum amount of ammonia will be required. The water carrier should remove all scrap rubber from the tree, so that the wound will be clean and fresh for the tapper.

Immediately following the water carrier comes the tapper, who rapidly freshens the wound or cuts a new channel, as indicated above, and passes on to the next tree. As soon as all of the water has

FIG. 1.—FRONT OF BAG, SHOWING WATER COMPARTMENTS, ONE FOR EACH VERTICAL CUT IN THE TAPPING AREA.

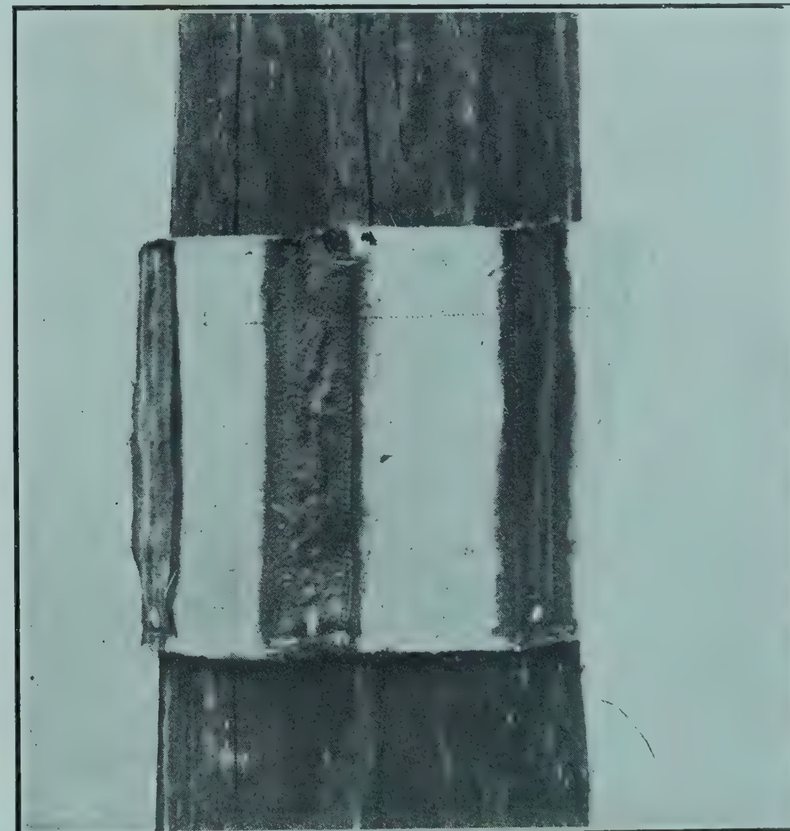

FIG. 2.—BACK OF BAG, MADE OF HEAVY CANVAS WITH THINNER CLOTH STRIPS OILED EXCEPT AT THE BASE OF EACH COMPARTMENT.

THE TAPPING BAG.

dripped out of the bags, collectors follow the tapping gang, emptying the containers into barrels or other receptacles for transportation to the coagulating house or central mill.

COAGULATION OF THE LATEX.

The first operation in coagulation is to strain the latex to remove particles of bark or earth or other large impurities.

A number of methods of coagulating latex are in use in rubber-producing countries. Among these are acetic acid, sulphuric acid, trichloracetic acid, common salt, alum, heat, evaporation, churning or agitation, and centrifugal force.

In the experiments which we have undertaken, as stated above, ammonia is added to the water which flows over the wound in the bark of the tree, made for the purpose of extracting the latex from the tree. The action of ammonia seems to be to retard coagulation. Latex containing moderate quantities of ammonia will remain without any appreciable coagulation for considerable periods, provided the mixture of water and latex is not violently churned, stirred, or shaken. In order to get rid of the ammonia, dilute sulphuric acid is added until the mixture shows a neutral reaction with litmus paper. The addition of sulphuric acid to a point of neutralization results in the formation of a small quantity of ammonium sulphate in the liquid. After standing for about one hour, a boiling concentrated solution of ammonium sulphate is poured into the neutralized latex and the whole is gently heated or is left standing. As the mixture is heated the rubber separates from the latex and water mixture and rises to the surface. The temperature of the liquid should not be permitted to go above 170° F., as the elasticity of the rubber is affected by high temperatures. The same results—that is, complete separation of the rubber from the water and latex mixture—can be obtained by allowing the latex to stand for a period of two to six hours after adding the ammonium sulphate solution, without heating, but the saving of time warrants the use of heat.

The rubber can also be coagulated by adding acetic acid without the use of heat. After adding the acid the mixture should be stirred or churned.

A very pure quality of rubber can be produced by the use of ammonium sulphate, because this salt precipitates the proteids, the proteids being compounds very liable to rapid decomposition. However, from the manufacturer's standpoint, it seems to be immaterial whether the rubber is free from proteids and other impurities.

Sulphuric acid is also a coagulant, but it should only be used in very dilute solutions.

Formalin may be used in conjunction with either ammonium sulphate, acetic acid, or sulphuric acid. When present in large excess, especially in the presence of ammonium sulphate, it has a rapid coagulating action. While the rubber produced by its use is of very high quality, the formalin preventing decomposition of the finished product, this compound is as yet too expensive for general plantation use.

Rubber may be obtained from the water and latex mixture without the use of ammonium sulphate by churning, by adding either acetic or sulphuric acid, with or without heat, or by simply allowing the liquid to stand until putrefaction begins.

One of the advantages of the collection of latex by means of water trickled over the wounds is the possibility of producing a product entirely free from bark, earth, twigs, and other gross impurities and adulterants. Where rubber has been collected from wild trees the common method has been to simply slash the trunk and branches, permitting the latex to flow down them or fall upon leaves placed on the ground beneath the tree. This method is a very wasteful one, and the rubber thus obtained is of uniformly low value because of the amount of dirt and other impurities. This method is not at all adapted to modern plantation conditions.

Every effort should be made to produce rubber of the purest and best quality; and it is believed that such rubber can best be produced from the Ceara tree by the use of considerable quantities of water in all of the processes connected with the collection and coagulation of the latex.

WASHING THE RUBBER.

As soon as all of the rubber has been separated from the latex it should be thoroughly washed in an abundant supply of fresh water. An important part of the washing process is to rub and knead the rubber. The tensile strength of the rubber is very much improved by thorough rubbing. For this rubbing and washing, either hand methods or machinery may be utilized.

After thoroughly washing and rubbing the rubber, it should be passed through a wringer to flatten the sheets and make them of uniform width and thickness.

DRYING THE RUBBER.

Two methods of drying are in vogue—by the use of vacuum pumps and low temperatures, or by placing the sheets of rubber on frames or shelves in drying houses so arranged that currents of dry air at low temperatures may be passed through the house. If a drying house is used, the rubber should be smoked during the drying process, but the temperature should not be allowed to go above 120° F. As

soon as the rubber is dry to the touch, and has lost about 25 per cent of its weight, it is ready to pack for market.

BALING THE RUBBER.

There is the widest variation in the form of packages and in the method of putting up rubber for shipment to market. It can be prepared in the form of biscuits, pancakes, sheets, lace, crape, or in blocks. It must be so packed as to economize space in shipment by ocean freight. Great care is necessary to protect it from moisture, so that there will be no deterioration through decomposition at any point from the plantation to the manufacturer. Rubber molds very readily and if the packages in which it is packed for shipment contain too much moisture, putrefaction occurs, the rubber becomes "tacky," and its selling price is greatly reduced. Every effort must be made to prevent decomposition, by drying, smoking, or coating the outer surface of the package with an antiseptic.

TAPPING EXPERIMENTS ON KAUAI.

Two groves of Ceara rubber trees were discovered on the island of Kauai during the summer of 1906 by Mr. Charles F. Judd, a forest ranger in the employ of the Territorial board of commissioners of agriculture and forestry. One of these groves, at Koloa, was planted about 1894. The grove at Lihue was planted five years later with seeds taken from the trees at Koloa.

THE KOLOA GROVE.

The grove at Koloa contains about 90 trees, only about one-third of these being of the original planting, the others being volunteer seedlings. The grove is very scattering, covering 4 or 5 acres. These trees, having grown at wide intervals, are much branched, with broad, spreading tops. The trunk of the largest tree in this grove is 47 inches in circumference, at 3 feet from the ground.

The land on which the Koloa grove is situated is very rocky, lying at the foot of the lower slope of the crater of Kalohana. The rainfall is abundant, probably averaging 60 inches per annum. The slope is toward the southwest. The location is protected from trade winds by the mountain spur above it, so that while the soil is not of the best, the complete protection from winds and the southern exposure make this location favorable for the rapid growth of any species of forest tree.

THE LIHUE GROVE.

The grove at Lihue is situated in a swampy gulch and is surrounded on all sides by a dense forest of ironwood and koa. This grove is about 9 years old, having been planted in 1898 by a German

forester in the employ of the Lihue Sugar Plantation. The trees are in rows about 12 feet apart and were originally at equal intervals in the row. They are very irregular in size, ranging from 12 to 42 inches in circumference at 3 feet from the ground. The trunks are mostly tall and slender, branching at from 3 to 25 feet. On account of the dense shade the branches are almost erect, very slender, leafy only at their extremities. The Lihue rubber trees are planted in an unsuitable location for this variety of tree. The ground is a bog at most seasons of the year. The ironwood forest, having made a more rapid and taller growth, has cut off the supply of sunlight from the rubber grove and the trees are in shade practically all of the time. There are about 110 trees in this group.

TAPPING THE LIHUE TREES.

Tapping experiments were begun at the Hawaii Experiment Station in Honolulu in December, 1906. This preliminary work was undertaken to find out something in regard to methods. Satisfactory preliminary methods having been worked out, a rubber-tapping experiment was undertaken at Lihue, Kauai, January 23, 1907.

After putting up a small house and getting tools, apparatus, and supplies together, tapping was commenced January 26, 1907. The method used was that of applying water containing ammonia to half-herringbone cuts in 3 trees. Using the water, the latex ran very freely for thirty minutes in 2 of the trees. In one of the trees the latex was yellow and hardly flowed at all. The amount of rubber obtained from this tree was very small and poor in quality.

On January 28 the trees were again tapped by freshening the old wounds. The tree with the yellow latex yielded no latex until the bark had been cut away for about an inch on each side of the original wound. At 2 inches from the original wound the latex flowed freely for three-quarters of an hour. The other two trees ran freely on freshening the old cuts. The latex from these two trees, after neutralizing with formalin, was divided into equal parts and allowed to stand for one hour. A boiling concentrated solution of ammonium sulphate was then added. Half of the liquid was boiled, the other half allowed to stand. The portion that was heated gave one-fourth of an ounce of dry rubber. The portion that was allowed to stand without heating yielded three-fourths of an ounce of dry rubber, much better in quality than that which had been heated.

On January 29 the same trees were again tapped by freshening the old wounds. The one with the yellow sap yielded very little latex—just enough to slightly color the water which was trickled over the wound. The other two trees continued to flow for one hour. The latex was then gathered, strained, and neutralized by adding 2 ounces of formalin per gallon of the mixture. It was then allowed

to stand one and one-half hours. The filtrate of ammonium sulphate and latex, which had been used in the preceding coagulation, on January 28, was poured into this while hot. After standing for thirty minutes the rubber was skimmed off the liquid. The result of this day's tapping was 1 ounce of pure rubber. The remaining liquid was divided into equal parts. One of these was heated and the other allowed to stand for three hours. The portion which was allowed to stand without heating yielded a second " cream " of rubber about the size of a sparrow's egg. That which was heated yielded a second cream of about three times as much. It took fully three hours to secure all of the rubber from the latex mixture.

On January 30 the same three trees were tapped by freshening the old wounds. The latex flowed about thirty minutes. The filtrate from the solution used on the previous day was strained through cloth and was poured into the fresh latex while hot. The latex was not otherwise acidified. In this day's tapping only one-fourth ounce of ammonia per gallon of water was used on the trees. This was markedly alkaline. The filtrate from the previous day showed an acid reaction. The latex mixture was left standing one hour and the rubber skimmed off, obtaining one-half ounce of pure rubber. A concentrated solution of 1 ounce of ammonium sulphate in water heated to boiling was then poured into the whole filtrate of about 2 gallons. It was allowed to stand for two hours. It was then skimmed of the second cream, yielding a little over one-half ounce of pure rubber. These tappings were from the ground up to a height of about 4 feet.

Because of an accident, through which the tapper was severely injured, work was not resumed until February 4. Two of the same trees were tapped from 4 feet up to 8 feet, using water containing ammonia at the rate of one-half ounce per gallon. The latex continued to flow for thirty minutes. The latex was divided into two portions. Into one of these the filtrate from the previous tappings was poured while hot. There was no coagulation after standing for one hour. This portion was again divided. One-half was placed over the fire, the other allowed to stand, and both began to coagulate at once. The remaining half of the fresh latex was divided. One-half ounce of acetic acid mixed with one of these portions coagulated the rubber at once. The other portion was neutralized with formalin and allowed to stand one hour. A concentrated hot solution of ammonium sulphate was then added. In about thirty minutes there was a marked clearing of the mixture, the milky portion of the liquid settling to the bottom of the vessel, but there was no coagulation of rubber until a trace of acetic acid was added, when it coagulated at once.

The quality of the rubber secured by using acetic acid was at first very poor, having practically no tensile strength, but after thoroughly washing and rubbing it became as elastic as any other. Apparently if acetic acid is used thorough washing is necessary.

February 5 the same two trees were tapped as on the preceding day by freshening the old cuts. The latex flowed for only about fifteen minutes. It was then collected, strained, and divided into three equal parts. To the first portion acetic acid was added. There was a rapid separation of the milky part of the liquid, but no coagulation of the rubber. There was no coagulation when this acidified latex was heated, but when a small amount of ammonium sulphate was added it coagulated at once. The latex of the second portion was acidified with acetic acid and cold ammonium sulphate added. There was no coagulation until the latex had been made quite hot. The filtrate left from the preceding day was heated and poured into the third portion of fresh latex. There was no coagulation until the mixture was placed over the fire.

The next day the trees were tapped as on February 5, from 8 to 14 feet above the ground. The latex flowed only fifteen minutes. There was practically no flow from one of the trees except a very little in the uppermost cut. The bark was so thin at this height that it was difficult to make a suitable cut with a knife without injuring the tree. The latex, acidified with one-sixth ounce of acetic acid, and to this a hot solution of ammonium sulphate in 8 ounces of water added, yielded only a trace of rubber. There was no coagulation until the mixture had been boiled some time. Another portion of this day's latex, acidified with formalin, allowed to stand one hour, a hot solution of ammonium sulphate added, and the whole boiled, gave only a trace of rubber.

The remaining portion of the latex, acidified with acetic acid, allowed to stand one hour, and boiled, without the addition of ammonium sulphate, gave no better results.

The latex from the upper portion of the trees is very thin and watery and contains less rubber than that from the lower section of the trunk.

On February 7 these two trees were again tapped at the same height. The latex flowed fifteen minutes. One and one-half gallons of the mixture was acidified with $1\frac{1}{2}$ ounces of acetic acid. It was left standing one hour without heating or adding ammonium sulphate. The rubber coagulated and creamed.

To another portion of this day's latex a portion of the acetic acid filtrate from the previous day was added without coagulation.

A third portion was left standing seven hours without being acidified; acetic acid then added, and allowed to stand overnight. Only

a very small amount of rubber coagulated from this portion in twenty-four hours.

On February 8 the old cuts were freshened and the latex flowed for twenty-five minutes. It was collected and divided into three portions. The first portion, amounting to 1 gallon, was acidified with one-third ounce of acetic acid and allowed to stand. A second equal portion was acidified in like manner and violently stirred. The foamy scum which gathered on the surface of the liquid contained some rubber, and when the mixture was heated all of the rubber in the liquid coagulated at once. A third portion was acidified with acetic acid and at once heated. In five minutes the greater portion of the rubber had coagulated. It was left until it had boiled fifteen minutes, when the filtrate was perfectly clear. This rubber was very elastic, but lacked tensile strength. Continued boiling makes the rubber soft and sticky and robs it of both its elasticity and tensile strength. Upon cooling both of these qualities were restored to some extent.

The same two trees were tapped February 9 by freshening the old cuts and the latex flowed for twenty minutes. After straining it was divided into two portions. One of these was placed in a churn without acidifying and churned ten minutes without coagulation. It was then acidified with acetic acid and again churned seven minutes, when the filtrate was perfectly clear. The rubber was in very small particles, closely adhering to the wood of the churn.

The second portion was heated fifteen minutes without acidifying, when a part of the rubber coagulated. It was then acidified, but no additional rubber was obtained.

On February 11 the old incisions were freshened. The latex flowed slowly for fifteen minutes. A portion was boiled for three hours without acidifying, only a trace of rubber being secured, the liquid remaining milky.

Another portion was acidified and churned five minutes until all the rubber had coagulated in small pieces as before. A third portion was heated with sea water in proportion of 1 to 3. Very little rubber was obtained even when, after boiling, it was churned.

February 12, tapped the same two trees by freshening the old wounds. The latex flowed twenty-five minutes. It was divided into two equal portions. One lot was acidified and the other churned one hour without acidifying. No rubber was secured from either lot. This lot was left in the churn overnight. It had not coagulated in the morning. After acidifying, a part was again churned and a part was heated for one hour. The lot left in the churn did not coagulate, while that which was heated produced some rubber.

The trees were tapped by freshening the old wounds February 13. One tree flowed for twenty minutes, the other did not flow at all.

Part of the latex was acidified with acetic acid and heated to boiling for one hour. The rubber coagulated, but was all in small particles.

On February 14 the old incisions were freshened. One tree flowed twenty minutes, the other not at all. The methods of the preceding days were repeated, but there was only very slight coagulation of rubber.

On February 15 the trees were again tapped. One flowed fifteen minutes, the other almost not at all. To one portion of the latex dry sulphur was added. It was then brought to a boil and removed from the fire and acidified with acetic acid. A little rubber coagulated at once. There was complete separation of the milky liquid, but the rubber sank to the bottom. After cooling it was again boiled, when a part of the rubber again creamed. This rubber was very soft and not elastic. Another portion, acidified and churned one-half hour and then allowed to stand four hours, coagulated a small amount of rubber.

Again, on February 16, the old wounds were freshened. One tree flowed for fifteen minutes, the other not at all. Acetic acid was added to one portion and it was allowed to stand one hour, at which time there was no coagulation. Hot concentrated ammonium sulphate was then added and it was left standing thirty-six hours. While there was a clearing of the liquid, there was no coagulation until the mixture was heated. It coagulated, but did not agglutinate until it had been pressed together with the hands.

The last tapping experiment with these trees was made on February 18. One tree flowed twenty minutes, the other not at all. The latex was acidified with acetic acid and allowed to stand for one hour; ammonium sulphate added; allowed to stand for one-half hour without coagulation; after churning for ten minutes coagulation was rapid, and the rubber was very elastic.

TAPPING TO DETERMINE YIELDS.

After continuing these tapping operations for about a month to determine the best method of coagulation, it was decided that the most uniform coagulent was acetic acid. What may be called the acetic-acid method of coagulation is the addition of just enough of the acid to the ammoniated latex to slightly acidify it and allowing the mixture to stand. The greater the amount of acid added the more rapidly will the rubber coagulate. A modification of this method is to neutralize with acetic acid and add a boiling concentrated solution of ammonium sulphate. It is believed that the rubber produced in this manner is more pure than that coagulated with acetic acid alone, because of the greater precipitation of the proteids by the ammonium sulphate. However, when both acetic acid and

ammonium sulphate are used the mass of rubber is very vesicular. The bubbles that are formed in the rubber mass are filled with the watery filtrate, which tends to render the drying of the rubber a slow and difficult process. Rubber coagulated by means of an excess of acetic acid is apparently fully as strong, although perhaps not quite so pure, and does not contain these vesicles.

During the period from April 5 to April 15, 8 ounces of dry rubber were obtained from two trees in nine tappings. The trees were tapped by the full-herringbone system from the ground to a height of 5 feet. The lateral cuts were 1 foot apart. The tapping was between 4 and 6 o'clock a. m. Ammonia was added to the water used in washing the latex from the wounds at the rate of one-half ounce per gallon. When the latex had stopped flowing, it was gathered, strained, acidified with acetic acid, and then a concentrated solution of ammonium sulphate was added. The mixture was then heated. As soon as the rubber had creamed it was skimmed and then washed and rubbed in an abundance of pure water. The rubber was not weighed until it had been thoroughly dried.

From April 17 to April 19 four trees were tapped, two each day on alternate days, to compare the results with every-day tapping. There was a slight increase in the yield in favor of the trees tapped every day. From July 15 to July 23 the two trees tapped between April 5 to 15 were again worked, using the same methods. The bottom and top laterals yielded as much latex as before, but the intermediate incisions yielded nothing. These two trees yielded $3\frac{1}{3}$ ounces of dry rubber as a result of nine tappings. At the same time one tree was tapped, using five vertical incisions from the ground to a height of 5 feet, with an oblique incision at the base, so as to bring all the latex to one container. This one tree yielded $3\frac{1}{6}$ ounces of dry rubber in nine days. This rubber was coagulated with sulphuric acid.

From July 26 to August 3 two trees were tapped daily from 5 feet up to 10 feet, using the half-herringbone system. These trees were 36 inches in circumference at 3 feet from the ground. They yielded $2\frac{3}{4}$ ounces of dry rubber in nine days. On July 27, a close, foggy morning, the latex only flowed in tears, which would have coagulated on the tree had not water been applied to wash it down.

On August 6 twenty-four trees were tapped, using the half-herringbone system, from the ground up to 4 feet, and $7\frac{1}{2}$ ounces of wet rubber were secured on this day. It was noted that there was wide variation in the amount of latex yielded by different trees, some yielding only a very little, others flowing freely. Acetic acid was used in coagulating this day's rubber.

On July 31 one tree that was very much branched was tapped, making half-herringbone incisions on each branch to a height of 5

feet from the ground. One-half ounce of rubber was secured. This concluded the work at Lihue from January to July, 1907.

TAPPING IN THE KOLOA GROVE.

During the period from May 21 to May 30 two of the oldest and largest trees in the Koloa grove were tapped, using the full-herringbone system from the ground up to 5 feet. These two trees averaged 44 inches in circumference at 3 feet from the ground, and both branched at about 6 feet. These had been much scarred and hacked by persons who had chopped or cut away the bark to see the latex run. There were a number of wounds that had not healed over, and the whole trunk of the tree was so rough that not all of the ammoniated water and latex could be collected at the foot of the tree. These two trees yielded 18 ounces of washed rubber in nine days' tapping. A good deal of the latex was wasted on account of inequalities in the bark. It is believed that had vertical incisions been used, instead of the herringbone, a very much larger yield of rubber would have been obtained.

From June 20 to June 28 two 4-year-old trees, 19 inches in circumference at 3 feet from the ground, were tapped by the herringbone system. These trees were bare of foliage, and yielded only three-fourths of an ounce of dry rubber in nine days.

From August 19 to August 28 the two trees tapped from May 21 to May 30 were again tapped by freshening the old incisions. The trees were in new leaf. The flow of latex was very slow at first, but increased each day until the end of the period. The largest yield of rubber was secured on the last day of the experiment. The two trees yielded 6 ounces of dry rubber in nine tappings.

On August 30 one tree was tapped, using the vertical method and coagulating with acetic acid and ammonium sulphate. The rubber from these tappings was lost on account of becoming moldy, so that no weights were taken. This tree yielded as much as any other two trees together. Between September 7 and September 20 the two 4-year-old trees tapped in June were again worked, this time yielding about one-eighth ounce of dry rubber at each tapping. During this period one large tree that had not been previously tapped was tapped from the ground to 7 feet with eight vertical incisions. It yielded only one-third ounce of washed rubber. The latex came out in small tears, and did not flow until ammoniated water was trickled over it. This tree was 40 inches in circumference. The latex was very yellowish, similar to one in the Lihue grove, which yielded practically no rubber.

No further tappings were made on the Kauai trees during 1907.

CONCLUSIONS.

The tapping experiments thus far undertaken, both on the Kauai trees and on various trees on Oahu and Hawaii, complete records of which have not been kept, indicate that there is very wide variation in the amount and quality of the latex yielded by individual specimens. It is therefore believed that every tree in every rubber plantation should be tested to determine the quality and quantity of latex before the tree is 2 years old. When individuals are discovered which yield an inferior quality of latex, or from which the latex does not freely flow, these trees should be rooted out and their places filled with cuttings from trees which appear to be of superior quality. In making these preliminary tests, it must be remembered that the flow from all rubber trees is poor on bright days, on the sunny side of the tree, and during the period of early leafage after the resting stage. The trees should be tested during the period of the day when the flow of the latex is highest—that is, between midnight and 8 o'clock in the morning. Wrong conclusions might be drawn from testing later in the day.

There seems to be some relation between atmospheric conditions and the flow of latex. Just what it is has not as yet been determined.

Double the amount of rubber can be procured from any Ceara tree by trickling water containing ammonia over the tapping area than by tapping without the use of water. The use of water will, it is believed, cheapen the cost of production rather than increase it. This method lends itself to rapidity of movement on the part of the tapping gangs and almost absolutely cuts out the production of scrap or waste rubber. The gathering of scrap rubber is more expensive than manipulating the water bag, and while one man working alone could not tap as many trees using water as not using it, by placing cloth water bags on each tree, so that they can be rapidly filled each morning before tapping, a very satisfactory system can be worked out.

It is believed that daily tappings for a period of two to four weeks or more will yield much better results than tapping on alternate days or at longer intervals over a period of several months. In our preliminary experiments, daily tappings for a period of nine days gave better results than tapping on alternate days for double the time, and the recovery of the tree was more rapid.

Trees which were tapped either just before the resting period or during the time when bare of leaves did not leaf out as quickly as neighboring trees which had not been tapped.

Young trees are not so readily injured by too deep cutting as old trees. The wounds in young trees heal very rapidly.

AMOUNT OF RUBBER PLANTED.

By January, 1908, 400,000 rubber trees had been planted in Hawaii, upwards of 90 per cent being *Manihot glaziorii*. The remainder are *Castilloa elastica* and *Hevea brasiliensis* in about equal proportions. There are now five large plantations in operation, and rubber trees are being planted by many independent farmers and planters. The oldest plantation is one of those at Nahiku. A first tapping will be made on some of the trees of this plantation during the summer of 1908, or as soon as they have reached a circumference of 20 inches, which is considered to be the smallest size at which it is safe or convenient to tap.

THE RUBBER OUTLOOK.

The whole tropical world is entering into the cultivation of rubber on a wholesale scale. Rubber is practically the only staple crop the supply of which has always come from what may be called natural sources. Even with the increase in the number of plantations during the last ten years 99 per cent of all of the rubber of commerce has been procured by the most wasteful and destructive methods from natural rubber forests. The rubber gatherer has preceded the tax collector in searching the unexplored and unknown forests in the interior of South America and all over the African Continent. He has destroyed forests and exterminated species in a relentless effort to secure enormous returns without the investment of proportionate capital. Wherever the rubber collector has gone no other need follow.

The cause of this frantic search for rubber-producing trees is to be found in the multitudinous uses to which this valuable material may be put. Because of its increasing scope of usefulness the rubber consumers have never been able to procure enough of the raw material to satisfy the yearly demands, so that the end of every decade has witnessed a marked increase in its value.

While it has been long recognized that certain species of rubber-producing trees, notably the Para and Assam rubbers (*Hevea brasiliensis* and *Ficus elastica*), were amenable to cultivation, tropical planters have only recently awakened to the enormous possibilities of a cultivated product which in its raw condition commands a price of $3,000 a ton or more. There is now apparently a race among countries having lands available for rubber production to see which can get the largest acreage of rubber trees into bearing in the shortest time, in order to harvest the marvelous profits which seem almost absolutely certain.

The present acreage of cultivated rubber probably exceeds half a million acres, and every year sees additional tens of thousands

of acres planted. One of the uncertain factors has been the time which must elapse between the first investment in land, seed, and plants and the realization of the planters' golden dreams. Hundreds of rubber-plantation companies have been formed and floated in Europe, the United States, Mexico, and the East Indies, some to operate concessions containing areas of wild trees, others seeking in all haste to plant as large an acreage as possible of one or the other species of rubber-producing plants.

While the uses of rubber are capable of almost indefinite extension, and while new purposes to which this material may be put are discovered every day, the very large areas which have been and will be planted will undoubtedly seriously affect present prices as soon as large areas have commenced to bear. At the present cost of production and at the present market returns the profits are enormous. If prices fall to a third of those of the present day, plantations already in operation will be able to continue to produce rubber at a profit of at least 100 per cent. It will doubtless be with rubber as it has been with all other raw products—that the cheapening of price will increase the consumption. The profits already obtained from the cultivation of rubber have been responsible for much extravagance in management and operation. No one can predict at what period the fall in prices will begin, but it will probably not be for another ten years at least and may not be in twice that time.

The best way to keep up the price is to produce only rubber of the best quality or of as good quality as is compatible with normal rather than extravagant management. When prices begin to go down, the plantations which will first feel it will be those in locations least suitable to the growth of rubber trees, or those which are overcapitalized or mismanaged.

The Ceara variety of rubber tree grows in Hawaii better than in its native habitat. The rapidity and vigor of growth on our plantations is remarkable. Many trees show a growth of from 10 to 15 feet or more during a single season, with girth measurements in proportion. While the trees on the Hawaiian plantations are more or less subject to fungus diseases and insect attacks, no specially destructive disease and no insect pest peculiar to this plant alone has as yet gained entrance to this Territory. The diseases and pests are those affecting forest trees in general.

The methods of tapping which this station has developed and the preliminary experiments already made indicate that healthy average trees of the Ceara variety, which have attained a trunk diameter of 6 to 8 inches at 3 feet from the ground, will yield from 5 to 10 or more pounds of crude rubber each per annum. As most of the Hawaiian plantations have made their beginnings on the prospect of securing 1 pound of rubber per tree per annum at the end of five

years, it is our sanguine belief that the cultivation of rubber trees of this variety is on as sure and firm a foundation in Hawaii as in any other part of the world. Furthermore, the Ceara variety seems better adapted to Hawaiian climate, soils, and conditions than any other rubber-producing tree which has as yet been introduced. Its extreme rapidity of growth and its adaptability to widely varying conditions of soil and climate, its large yields, and its early maturity indicate that its cultivation will be the most advantageous.

INSECT ENEMIES OF THE CEARA RUBBER.[a]

The following information occurs in the entomological records of this station regarding the insects injurious to the Ceara rubber tree in Hawaii:

SEED BEDS.

A wireworm (*Elateridæ*, species undetermined) destroyed many seeds in the seed beds at Nahiku the first season. The source of the pests was traced to the horse manure used in the seed beds, the manure heap offering a breeding place to the larvæ of this beetle. The wireworms entered the seeds through the openings made in filing, feeding on the interior. Seeds that were not filed through escaped injury from wireworms. Sterilization of soil and manure used in seed beds as described above for nematodes will check the development of this pest.

THE TREE.

The following scale insects (Coccidæ) have been taken from Ceara rubber trees in Hawaii: *Saissetia nigra*, *Saissetia oleæ*, *Aspidiotus cyanophylli*, and *Pseudococcus* sp. (mealy bug).

In no instance had serious results attended the presence of these insects. Lack of injury is due largely to the young and vigorous growth of the trees. The vigor and health of the trees must be maintained.

A bark beetle, *Xyleborus affinis*, followed injury to the tree from tapping on Kauai. The snout beetle, *Pseudolus longulus*, likewise found entrance in the unhealed scars from tapping. The former species was rather abundant in the single case observed and gave evidence that under favorable conditions for development it might work serious injury. The latter species is not considered important. Both species are borers. Care must be exercised in keeping all dead and partly dead limbs and trees cleared away, and all wounds from tapping that do not heal over should be painted as soon as the tapping is discontinued to prevent these borers from gaining entrance.

[a] By D. L. Van Dine, Entomologist.

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HAWAII AGRICULTURAL EXPERIMENT STATION
E. V. WILCOX, Special Agent in Charge

BULLETIN No. 18

INSECTS OF COTTON IN HAWAII

BY

DAVID T. FULLAWAY,
ENTOMOLOGIST

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS
U. S. DEPARTMENT OF AGRICULTURE

HONOLULU, HAWAII:
PARADISE OF THE PACIFIC ENG. AND PRINT
1909

HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. True, Director of the Office of the Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS,
Chief of Division of Insular Stations, Office of Experiment Stations.

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *May 15, 1909.*

SIR: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 18 of this station a manuscript on the insects of cotton in Hawaii, prepared by Mr. David T. Fullaway, entomologist. This paper gives accounts of all the insects thus far known to attack the cotton plant in the Hawaiian Islands, together with suggestions for their control. There is a growing interest in the possibility of cotton-raising in Hawaii, and following the policy of assisting in the diversification of the agriculture of the islands the station is endeavoring to promote the establishment of this new industry. The illustrations are believed to be necessary to the proper recognition of the pests enumerated.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE,
Director.

Publication authorized.
JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

REPORT ON THE
INSECTS WHICH AFFECT THE COTTON PLANT
IN THE HAWAIIAN ISLANDS

By DAVID T. FULLAWAY, Entomologist.

INTRODUCTION.

The present interest in the possibilities of cotton-growing in these islands required that some attention be given to the insects which affect the cotton plant, for whether the crop can be grown profitably or not will depend in large measure on the extent to which the yield is diminished or damaged by insect attacks. Although it has been more than seventy years since the first cotton was planted in the islands, its growing up to the present time has not been one of the agricultural industries, and one attempt at least to make it so was without success. For the past two or three years, however, three varieties of cotton, Sea Island, Caravonica, and Chinese, have been grown experimentally on the grounds of this station with remarkably promising results. While the damage to the yield by insects was by no means inconsiderable, it was easily demonstrated that cotton of a fine grade and large yield could be grown under favorable conditions.

The writer desires to acknowledge the assistance received in the preparation of this bulletin from co-workers in Honolulu and elsewhere, to whom he expresses his warm thanks.

The insects are treated in the order in which they attack the plant.

STEM MAGGOT.

Cotton recently planted in Honolulu was noticed soon after germination to be affected by a stem maggot. Only a small proportion of the plants were attacked, but in each case the plant was killed, making replanting necessary. The maggot was found within the stem and above the point of attack the circulation was completely stopped. As a result of such injury the plant wilts and ultimately dies. Below the point where the maggot was working the stem was abnormally swollen. Up to the present time attempts to breed the fly from the maggot have not been successful. It is, however, likely to be a common species, as carnations and pigeon-peas have been noticed to suffer similar attacks.

WIREWORMS.

Wireworms (the larvae of Elaterid beetles) are unfailingly present in the soil here, in which they feed naturally on the roots of weeds and decaying vegetable matter. From these they readily turn to cultivated plants, especially tender seedlings. They are easily distinguished by their elongate, wire-like form, their shiny yellow or brown color, and their hard, inflexible integument. The one attacking germinating cotton is probably the larva of *Simodactylus cinnamomeus* Boisd., although other species may be implicated.

Fig. 1.-Wireworm, enl. (Original.)

Wireworms attack the cotton usually just beneath the surface of the ground. The injury is not strikingly apparent except in its results—the withering of the plant—but close observation will disclose that the parenchyma is destroyed for the space of an inch or two, which turns brown. Wire-worm attacks, in some instances, have been quite severe, as large a proportion as one-third of the plants in a field being destroyed. The necessitated replanting constitutes a serious setback to the crop.

CUTWORMS.

Of the several insects injuring the cotton plant in the early stages of its growth, cutworms undoubtedly do the greatest damage. From the time the seedling gets above the surface of the ground until it is a foot or more in height and has begun to square out, it is subject to the attacks of these extremely voracious and ubiquitous larvae. The cutworm that has been observed to attack cotton most frequently is the larva of the common moth, *Agrotis ypsilon* Rottenburg, although the larvae

Fig. 2—Cutworm and moth, *Agrotis ypsilon* Rott. Both twice nat. size. (Copied from Swezey.)

of *Heliophila unipuncta, Agrotis saucia, A. dislocata* and *A. crinigera* have similar habits and may also attack cotton. Mr. O. H. Swezey,[a] assistant entomologist of the Hawaiian Sugar Planters' Experiment Station, gives the following account of the life-history of *Agrotis ypsilon:*

"The eggs are domeshaped, about 0.5 mm. in diameter, and creamy white in color. There is a small circular depression at the upper pole

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[a] Hawaiian Sugar Planters' Expt. Sta., Div. Ent. Cir. 5.

from which radiate numerous ridges running down the sides to the base or surface in contact with a leaf. The eggs are laid on the surface of leaves or stems of plants near to the ground. From one to many eggs may be placed close together in one batch, and one moth may produce several batches amounting to two or four hundred eggs.

"The larvae hatch from the eggs in a few days (usually two to four). They molt five times at intervals of two to six days and become full-grown in about one month. The full-grown caterpillar is about 1.75 inches long (45 mm.). It is of a nearly uniform dark, greasy-gray color, paler below. The spiracles are black. The tubercles are conspicuous, showing as regular rows of brownish dots. Head and dorsal part of segment behind head dark brown.

"The pupa is formed in an earthen cell a little below the surface of the soil. It is about .75 inch long (20 to 23 mm.), uniform medium brown in color, with a dark dorsal band at apex of abdominal segments 4, 5, 6 and 7, containing irregularly arranged small pits. At the tip of abdomen are two large tapering spines, black at base and pale at tip, a little distance apart at base, slightly diverging but curved together at their tips.

"The moth emerges from the pupa in ten days to three weeks. It is about two inches in expanse of wings. It is of a dark gray color with black eyes and collar. The fore wings are velvety blackish brown except the outer one-third, which is paler brown. There is a distinct U-shaped black mark a little beyond middle of wing, a black dash extending from its outer side, and two black dashes farther toward the end of the wings. Hind wings light gray, brown on outer margin and on veins."

He says of it:

"It is a well-known garden cut-worm throughout the United States. It ranges in America from Hudson Bay south to Uruguay, is common in Europe, also occurs in northern and southern Africa, India, China, Japan, Java, Australia and New Zealand. It is a typical cutworm in its feeding habits, i.e. feeding on plants at night-time, often cutting off small plants at or below the surface of the soil, and hiding under leaves, trash, or burrowing in the soil during the daytime. It is a very general feeder, attacking nearly all kinds of garden and field crops and even weeds. * * * In the United States they are particularly troublesome to corn, cotton, cabbage, tomato, and tobacco, attacking the young plants, one cutworm often destroying several plants in one night. In India they are destructive to young tea and coffee plants and opium."

As Mr. Swezey observes, the cutworms are night-feeders. Their method of attack is to eat directly through the stem, cutting it off just above the level of the ground. They are usually present in large numbers and inflict incalculable damage. If, as is often the case, half of the plants in a field are attacked and replanting becomes necessary, with the consequent setback to the crop, cutworm injury becomes a serious matter indeed. Replanting to such an extent may be avoided

by planting several seeds in a hill, in the hope that some of the plants may escape attack, but even this measure might be ineffective in a badly infested field.

Remedies: Perhaps the best remedy for cutworms and wire-worms is found in the use of poisoned baits. These are prepared by combining a poison—such as arsenic—with some food substance for which the cutworm has a decided taste. White arsenic is most generally used, either on freshly cut alfalfa, or combined with molasses, cane sirup or honey and mixed into bran, middlings or flour. Use one pound of arsenic to ten of bran. Fifty to seventy-five pounds should be sufficient for one acre.

Cutworms are kept in check to some extent by dipterous and hymenopterous parasites as well as by birds.

APHIDS.

Cotton suffers more or less from aphids all the time, and at certain times or seasons the damage by these insects becomes a great handicap to the plant. On germinating seedlings aphid attack is serious and threatening, often demanding active measures to save the plants. Specimens of the aphid on cotton recently submitted to the Bureau of Entomology, United States Department of Agriculture, were determined by Mr. T. Pergande to be the well-known species, *Aphis gossypii* Glover. This species is a common pest of cotton in the United States, but there it is heavily parasitized and consequently, as a pest, of little importance. In these islands, as far as is known, it is unparasitized, although fairly well kept in check by Coccinellids and other predaceous species.

Aphid injury is at a minimum during the hot, dry months of April, May, June, July, August, September, and October. With the oncoming of the cold and wet weather in the latter part of November and through December, indeed through the remaining months—January, February, and March—aphids are likely to do considerable damage to cotton, although any abnormal increase is soon brought in check by ladybirds.

Remedies: When germinating plants are threatened by aphid attack, the liberal use of tobacco dust is considered advisable. Tobacco dust is a cheap insecticide and is easily applied. Mature plants should be sprayed with kerosene emulsion.

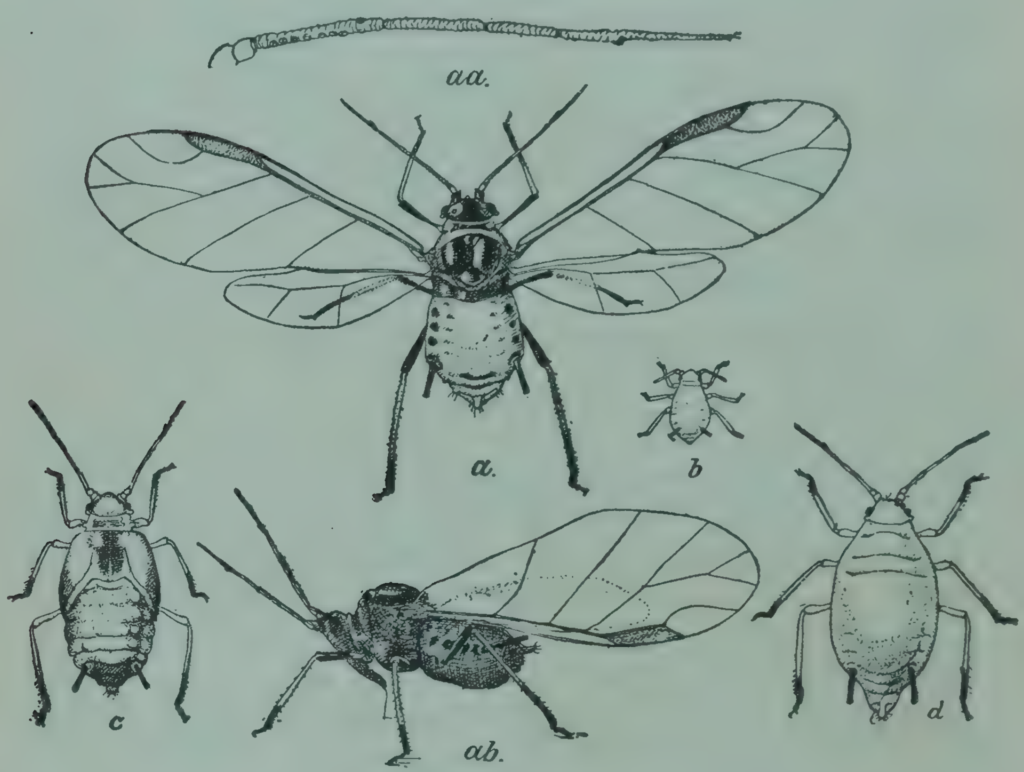

FIG. 3—Cotton aphis, *Aphis gossypii* Glov. *a*, winged female; *aa*, enlarged antenna of same *ab*, dark female, side view, sucking juice from surface of leaf; *b*, young nymph or larva; *c*, last stage of nymph; *d*, wingless female. All greatly enlarged. (Copied from Chittenden.)

The introduction of the common parasites of the cotton aphid from the United States seems entirely feasible, and could only bring the most beneficial results.*

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* An effort is being made by this Station to secure aphid parasites through the cooperation of the Bureau of Entomology, U. S. Department of Agriculture.

JAPANESE BEETLE.

The so-called Japanese beetle, *Adoretus tenuimaculatus* Waterhouse, has injured cotton to some extent, attacking the foliage. It has not been considered as serious a pest with regard to cotton as it has with other cultivated plants, although a small planting of Chinese cotton was utterly defoliated by it. This variety seems to be especially susceptible, while the Caravonica cotton shows little susceptibility to attack.

FIG. 4.—Japanese beetle, *Adoretus tenuimaculatus* Waterhouse. Natural size indicated by line. (Copied from Kotinsky.)

MEALY BUG AND SCALE INSECTS.

Two serious pests of cotton are found in the mealy bugs (Coccidae) known scientifically as *Pseudococcus virgatus* (Ckll.) and *Pseudococcus filamentosus* (Ckll.). Neither of them is confined wholly to cotton, each having a long list of hosts among both wild and cultivated plants. For this reason their attacks are likely to be more or less intermittent and perhaps negligible. An outbreak of either in the cotton field, however, would result in considerable damage to the crop and would be most difficult to control by artificial means.

FIG. 5.—*Pseudococcus virgatus* (Ckll.) Adult female. (Photograph by author.)

Pseudococcus virgatus is a common pest of cultivated plants in several countries. Cockerell discovered it in Jamaica on cultivated violets, algaroba, and other wild plants; Koebele

found it in Mexico (at Cuautla in Morelos) on coffee; and it is also reported to occur in Mauritius. In addition to the host plants already mentioned, cactus, cocoanut palm, *Acalypha* and *Tribulus cistoides* are given. In these islands it has been found on *Dolichos lablab,* poinsettia, oleander, violets, litchi, and klu as well as on cotton. The species is recognized by its elongated shape and the peculiar character of its white waxy secretion, which appears flake-like and glassy. The secretion of immature specimens takes the form of long slender glassy threads, which project from head, back and sides in all directions, forming a sort of web. There are, besides, two long white waxy caudal filaments but no apparent lateral filaments except the fine filamentous threads already referred to.

Life history. The eggs are minute, oval, and golden yellow. A single female will deposit apparently several hundred or more. The eggs hatch within a day or two. There are two larval stages characterized by six and seven jointed antennae respectively. The first larva measures 0.3-1 mm. The second larva 1.5-1.8 mm. The adult female has 8 jointed antennae and is 2 mm. in length. The first larval stage occupies twenty days, the second larval stage eight days, the latter giving place to the adult female. Coincident with the appearance of the adult female occur the male pupae, and six days later the male itself emerges. Copulation takes place at once. The male, as is usual in the Coccidae, is much inferior in size to the female. It has two chalky-white, iridescent wings, long caudal filaments, and antennae with ten joints. After fecundating the female the male soon perishes. The female survives until its eggs are formed and deposited, which may require weeks. While the eggs are forming its body becomes tumid and vastly increased in size. The life-cycle may be said to cover at least two months. Apparently the species breeds uninterruptedly throughout the year. With its great fecundity and rapid growth, its ability to increase in enormous numbers and become a pest is not at all surprising. It is, however, undoubtedly held in check by climatic conditions as well as by natural

enemies, chief among which are the many introduced species of Coccinellidae (ladybirds).

The following technical description is inserted to facilitate the determination of this species by entomologists, or anyone who may have access to a compound microscope:

"Female—4½ mm. long. Very white, mealy brown above except dark purplish gray subdorsal stripes which are broadly interrupted centrally. Caudal filaments about 2 mm. long, i.e. about half length of body. No obvious lateral appendages. Segmentation distinct. Beneath whitish, legs pale brown. The caudal filaments are rather slender but not filiform like those of *D. longifilis.* The lateral appendages seem to be represented by long and very fine hairs, which are obvious in the young but are lost in the adult. Very young individuals are pale yellow. Femur (of adult) about as long as tibia; tibia about three times as long as tarsus. Antennae with eight joints—3 and 8 subequal, or 8 a *little* longer; 2 sensibly shorter than 3; 4 rather longer than 5; 5, 6 and 7 about equal.

"Male brown. Antennae brown; all the joints with long hairs—3 longest, longer than 1 and 2, decidedly longer than last; 4 same length as 6; 5 a very little shorter than 4; 7 decidedly shorter than 6 and slightly shorter than 5; 8 same length as 7; 9 still shorter but not quite so short as 1; 10 same length as 5. The second joint, which is about as long as 7 or 8, is conspicuously enlarged, much thicker than the joints following."

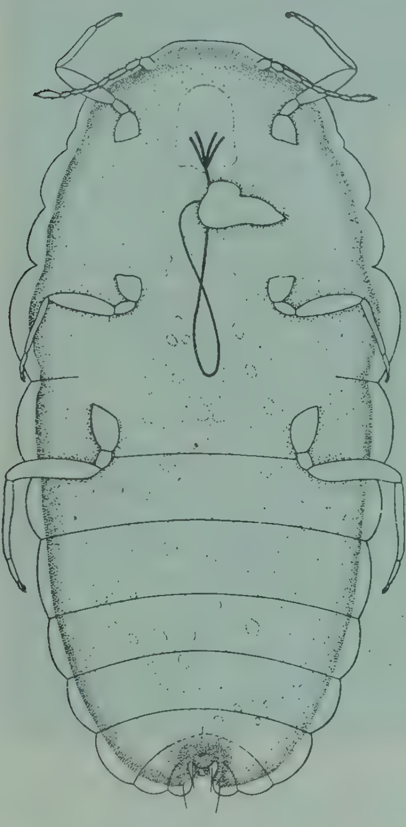

FIG. 6.—*Pseudococcus virgatus* (Ckll.) Adult female. (Original)

Pseudococcus filamentosus, perhaps the most destructive species of Coccidae in these islands, has been a pest of cotton for several years. It also attacks other plants—hibiscus, mulberry, grape, but chiefly citrus trees. According to Koebele, it was introduced about 1891, from Japan. It also occurs in Jamaica and Mauritius. It attacked citrus trees at first but

soon spread to all kinds of ornamental plants. Residents of Honolulu of fifteen years ago state that hundreds of trees were destroyed by it and that the trees were white with the insects as if covered with snow. About 1894 the Coccinellid beetle, *Cryptolaemus montrouzieri* Muls., was introduced by Mr. Koebele from Australia especially to prey on this pest. The ladybird became established and increased steadily. Since that time the

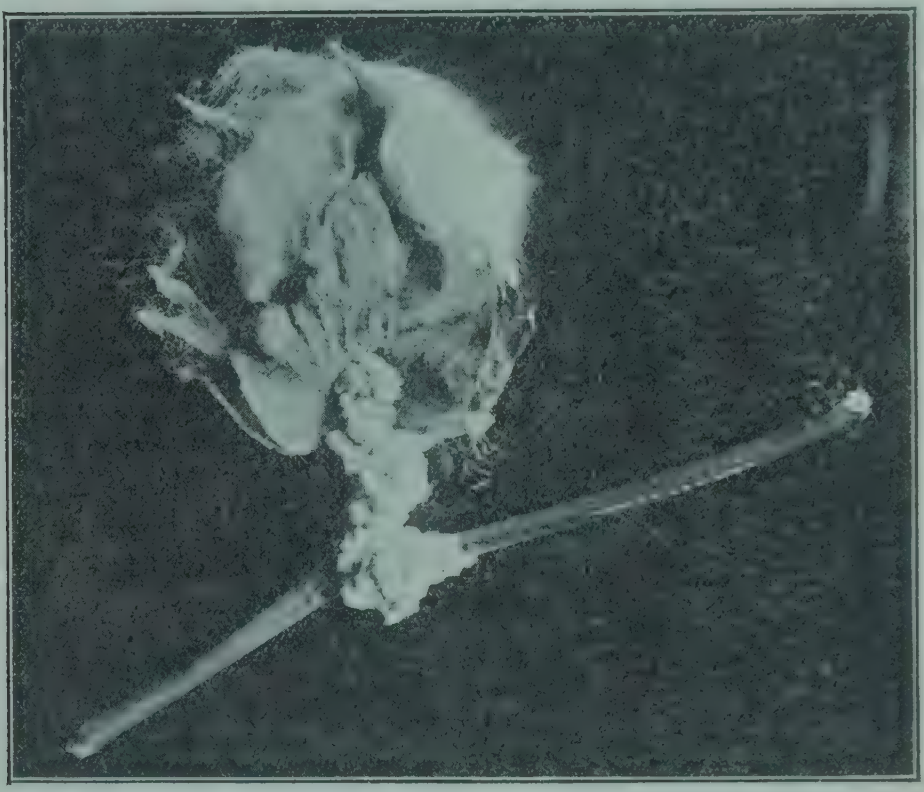

FIG. 7.—*Pseudococcus filamentosus* (Ckll.), showing globular egg-sacs clustered on cotton stem. (Photograph by author.)

ravages of *Pseudococcus filamentosus* have been greatly reduced, although occasionally the balance of nature is disturbed and *filamentosus* becomes injurious.

The species is readily recognized by the large clusters of yellow-tinged, globular egg-sacs which it forms on the stems and bolls of cotton.

Life history. The egg-sac contains several hundred eggs.

The eggs hatch in about fifteen days. The larva when hatched is naked but is soon covered by a white waxy secretion which becomes heavier as the insect increases in size. The larva is about one-ninetieth of an inch in length and is characterized by the possession of six-jointed antennae. The larva molts after 20 days, giving place to the adult, which is characterized by seven-jointed antennae. Immediately after the molt the insect is quite small; growth is very gradual and it takes several months for it to attain its full size and form the egg-sac. The male has not been observed.

The following technical description is inserted to facilitate the determination of the species by entomologists:

FIG. 8.—*Pseudococcus filamentosus* (Ckll.) Adult female; antenna; leg; larva. (Copied from Maskell.)

"Female insect covered by globular sacs of whitish or yellow cotton, which are frequently aggregated in large masses on the twigs. Diameter of sac about one-eighth inch. Sac of male pupa not observed. Adult female dark red or purple, slightly elliptical or subglobular. Length about one-twelfth inch. Segments inconspicuous. Antennae of seven joints, of which the seventh is the longest and largest and the fifth the smallest. The rest subequal, all the joints bearing a few hairs, which are most numerous at the extreme tip. Feet moderately strong. Tibia about one-third longer than the tarsus. There is not

any long hair on the trochanter nor any terminal spine on the tibia. The tarsal and claw digitules are all fine hairs. Anal ring compound with six hairs. Anal tubercles inconspicuous, setiferous. Mentum dimerous with some hairs at the end. Margin of body bearing a few small conical spines wide apart (sometimes absent), which are in pairs or threes on the abdominal segments; and similar spines are very sparsely scattered on the dorsum where there are also some scattered fine hairs. Epidermis bearing many circular spinnerets of two sizes, those on the dorsal surface being twice as large as those on the ventral.

"Larva dark red, flattish, elliptical, active. Length about one-ninetieth inch. Antennae thick with 6 joints, of which the last is the largest. Feet also rather thick. Tarsus longer than the tibia and digitules are all fine hairs. Anal tubercles normally with moderate setae. Margin of body with only a few very small spines.

"Male unknown."

There is also commonly found on cotton the so-called "black scale," *Saissetia oleae* (Bern.), a species that is widely distributed over the world, with a great variety of host-plants. Here it is not entirely confined to cotton, having been taken as well on sisal, Ceara rubber tree, guava and crotalaria.

It is usually found on the stem or branches of cotton, but never in great numbers, and it is hardly likely to be a serious pest, as its multiplication is checked by both internal parasites and ladybirds.

Remedies: The use of artificial remedies for the control of mealy-bug and scale insects is hardly warranted from a practical standpoint unless in an exceptional outbreak they should threaten the life of the plants. Ordinarily their multiplication will be kept within reasonable bounds by their natural enemies. In case of abnormal increase, the use of a strong nozzle stream of water from a force-pump, to dislodge the egg-sacs, eggs or old shells, followed by spraying with kerosene emulsion (strength 1 to 20), is likely to bring beneficial results.

The introduction of specific parasites for these destructive species, if such exist, is highly desirable.

BOLL-WORM.

Without doubt the worst insect enemy of cotton in Hawaii is the boll-worm, the larva of a Tineid moth, *Gelechia gossypiella* Sdrs. In many parts of the islands its ravages are unknown,

but in the experimental plantings at this Station and elsewhere in and about Honolulu it does great damage to the cotton crop. It is said to have been introduced (unquestionably from India) within comparatively recent years. It has doubtless spread to all the islands, having been reported to this office from Hawaii and Kauai; indeed, that it is not everywhere prevalent can only be accounted for by the small extent to which cotton has been grown.

Gelechia gossypiella is also a major pest of cotton in India. It has been known there for a quarter of a century and is said to have been introduced with Egyptian or American cotton brought in about 1883. Lefroy reports it as now generally present throughout the Indian Ocean region, in India, Ceylon, Burmah, Strait Settlements and German East Africa. The insect is also reported to have been collected in Japan, but Kuwana writes that it is not known there.

Lefroy says of it:

"The pest is apparently universal in India, Ceylon, Burma and the Strait Settlements, causing a very large aggregate loss to cotton in India, which may amount to at least one crore of rupees (over $4,000,000) annually. The destruction of the seed, the staining of the lint, and the loss of young bolls are the principal forms of damage. So far as is known all varieties of cotton now grown as field crops in India are attacked, the American and Egyptian as well as the indigenous. It remains to be seen whether there are any varieties of cotton immune to the pest, but none have definitely proved so up to the present. Unlike the other boll-worms, this species has not been found attacking plants allied to cotton; its wild food-plants appear to be trees with oily seeds which are widely distributed in India."

In Hawaii, according to Perkins, it attacks other plants than cotton. I have bred it from milo (*Thespesia populnea*).

The boll-worm, as its name indicates, attacks primarily the boll, although the immature worms sometimes enter the ovary and devour the young ovules, preventing the normal forming of the boll, which either drops or opens prematurely, before the lint has been formed. In the boll it causes premature opening, rotting and soiling of the lint. The worm also enters the seed, eating its contents. In a planting where no effort was made to control the pest it was estimated that fifty per cent of

the bolls and about fifteen per cent of the seeds were infested. If a field is badly infested, three or four worms may be found

Fig. 9.—Cotton boll showing egg of the bollworm *in situ*. (Photograph by author.)

in one boll, practically destroying the boll as far as its lint is concerned.

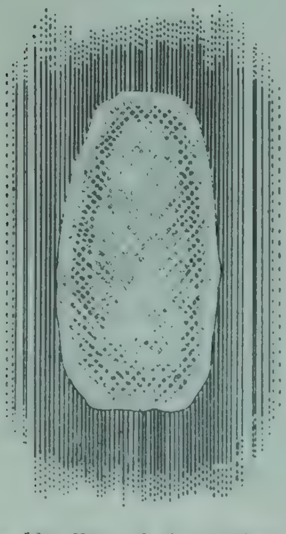

Fig. 10.—Egg of the bollworm, greatly enlarged. (Original)

Life history. There are four distinct stages in the life cycle of the bollworm, as in the case of all butterflies and moths—namely, the egg, larva, pupa, and adult.

The egg. The eggs of the bollworm are deposited singly on the leaves, bracteoles and bolls. They are quite small (about one-fortieth of an inch in longest diameter), flattish and pearly white. They are small enough to be quite inconspicuous and are detected only with the closest scrutiny. The peculiar sculpturing of the egg-surface, which ren-

ders them unmistakable when observed with a hand lens, is shown in Fig. 10. The number of eggs laid by a single moth may be quite large. The eggs turn red before hatching. The egg-stage occupies about ten days.

The larva. The larva is the destructive stage of the insect and the one in which it will be most generally noticed by the cotton-grower. When first hatched the larva is very small and may escape attention. For perhaps a day it moves about over the surface and then it commences to tunnel into the bud or boll. A very small hole with fine pellets of frass about its opening, perhaps the hind portion of the larva protruding, indicates the point of entrance. Within the boll it is hidden from view, but it is feeding and growing all the time, and when the boll bursts open a larva of considerable size will be found inside. At this time the larva has a characteristic appearance which renders it recognizable. It is about half an inch long and an eighth wide, its color a dirty white with four rows of dark-colored spots on the dorsum and one lateral row on each side, the head dark brown and the cervical and supra-anal shields mostly black. Each dark-colored spot on the back represents a protuberance, from which arises a hair, and around each spot is a suffusion of pink—which gives the larva the popular name of pink bollworm. The larval stage occupies about twenty-three days.

Fig. 11a—Bollworm, *Gelechia gossypiella* Sdrs., larva. Nat. size. (Photograph by author.)

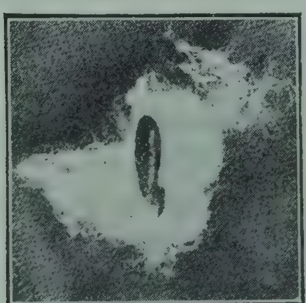

Fig. 11b—Bollworm, *Gelechia gossypiella* Sdrs., pupa. Nat. size. (Photograph by author.)

The pupa. The larva usually pupates within the boll, forming a light cocoon in the cotton square near the surface. The chrysalis is brown and three-eighths of an inch in length. It

turns dark just before the moth emerges. The pupal stage occupies about fourteen days.

The adult insect. The perfect insect or imago of the boll-worm is a rather small moth of a gray-brown color with dark blotches and suffusions. The wings expand about three-fourths of an inch. On the front wing there is a large dark area towards the apex. The hind wings are grayish. The fringe on the front wings is brown; it is longer on the hind wings and lighter in color. The moth flies at night and will seldom be seen in daytime. It flies with a swift, darting motion when disturbed. The female begins to lay her eggs in three or four days after leaving the chrysalis, and each individual lays a large number of eggs. The moths live from five to ten days or even longer after emergence.

FIG. 11c—Bollworm, *Gelechia gossypiella* Sdrs., adult moth. Nat. size. (Photograph by author.)

Remedies: The use of artificial remedies to combat the boll-worm is at the present time, for practical reasons, not advised. Relief, it is thought, is to be sought rather in clean culture and the use of certain cultural methods adapted to lessen boll-worm infestation. The regular destruction of infested bolls by burning; severe pruning and burning after the last picking in the fall; the collection and burning of all fallen bolls (clean culture); ginning soon after picking; picking and

FIG. 12—Parasite of the bollworm, *Chelonus blackburni* Cameron. Enlarged ten times. (Copied from Swezey)

burning any badly infested flush out of season;—all these are likely to keep bollworm injury at a minimum.

The boll-worm is to some extent parasitized by hymenopterous flies. The writer has bred *Chelonus blackburni* from it and others are reported. It is also parasitized in India. How effective parasites may be in reducing the ravages of the bollworm is only a matter for conjecture, but the introduction of effective parasites would be highly desirable.

The cotton bollworm of the Southern States, *Heliothis obsoleta,* has not as yet been found to attack cotton here. It often infests corn and has occasionally been bred from other plants. Its parasites are so efficient that it is not expected it will become an important factor in our cotton production.

LEAF-FOLDING CATERPILLAR.

A leaf-folding caterpillar (larva of *Archips postvittanus* Wkr. Tortricidae) affects cotton and does some, although more or less slight, injury to the foliage. The caterpillar is naked and dark green, the shield light colored, slightly brownish. When full-grown the caterpillar measures about an inch in length and is more or less slender. The chrysalis is naked, slender and dark brown. The adult moth has a wing-expanse slightly over one-half inch. The wings are pale brown with darker markings. It is not of sufficient importance to demand especial attention.

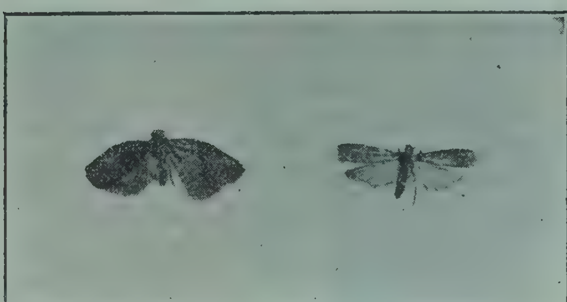

FIG. 13—Leaf-feeding caterpillars, a, *Archips postvittanus* Wkr. b, *Cryptoblabes aliena* Swezey, ms. sp., on cotton. (Photograph by author.)

The larva of the Phycitid *Cryptoblabes aliena* has also been found on cotton, but it probably does not feed on the plant, rather on the remains of insects. It is found in mussy places on the leaves and bolls. The full-grown caterpillar is naked,

brown-striped and about three-fourths of an inch long. The chrysalis is slender and brown. The adult moth has a wing expanse of less than half an inch, is pearly gray in color, the fore-wings darker than the hind ones.

An undetermined species of the genus *Myelois* has been

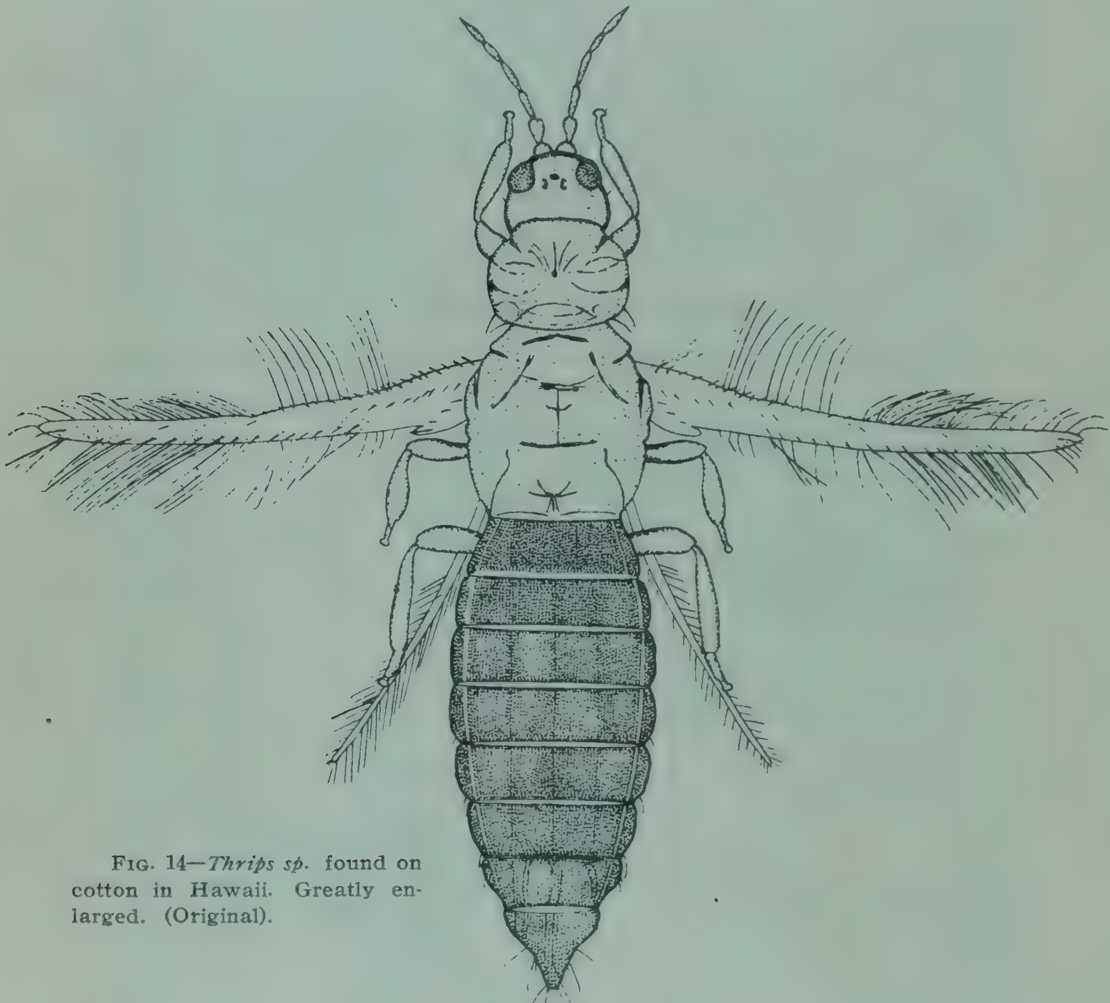

FIG. 14—*Thrips sp.* found on cotton in Hawaii. Greatly enlarged. (Original).

bred from infested cotton bolls. Its larva or caterpillar, about three-fourths of an inch long when full-grown and pale to reddish in color, probably feeds similarly to the Cryptoblabes larva. The moth is small and gray.

STEM BORER.

Insects boring into the stem of the cotton plant have not been observed until recently, although a careful watch has been kept for this class of injury. After a recent wind storm many broken stems and branches in the station planting revealed the work of a small black beetle, *Sinoxylon conigerum* Gerstacker. This beetle attacks dead wood and felled and seasoning timber, having been taken on previous occasions from *Acacia decurrens, Prosopis juliflora* and cotton stumps. It was probably attracted to the standing cotton because of the dry condition of the wood through lack of irrigation. The attacks are almost without exception at the origin of a branching shoot, and as the attacks of two or three beetles are usually concentrated at one point they may do great havoc in a plantation before their work is observed. At the same time it is not believed that they will attack actively growing plants and if this is so their injuries may be entirely avoided by keeping the land in good tilth so as to conserve its moisture.

MINOR PESTS.

Thrips. A species of Thrips is commonly found in the blossoms of cotton but seems to do very little damage. Specimens of the insect were referred to Washington for determination.

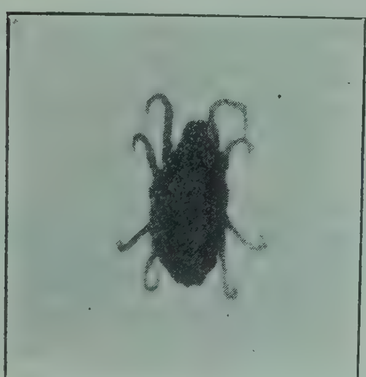

FIG. 15—Mite or red spider, *Tetranychus sp.*, found on cotton in Hawaii. (Photograph by author).

Red spider. A species of Tetranychus is also commonly found on the foliage or bolls of cotton. It is probably responsible for some spotting of these parts of the plant but outside of this does little damage, and has never been observed in large numbers. Specimens of this pest were also referred to Washington for determination.

Besides the injurious species already referred to there are three or four insects commonly found on or about cot-

ton without doing any particular damage as far as it is known. A species of Psocidae, determined by Mr. Nathan Banks as *Elipsocus inconstans* Perk., is found with great regularity on cotton, usually about withered leaves or bolls. It probably feeds exclusively on dry, dead vegetable matter and insect remains. Apparently it does no damage to the cotton.

Three coleopterous species, *Epitragus diremptus, Araeocerus fasciculatus* and *Ompatrum serratum,* are also found about cotton, probably seeking shelter. The last-named species is usually found on the open ground or under trash piles; the two first in crevices in the bolls. Of *Araeocerus fasciculatus* Dr. Howard says:

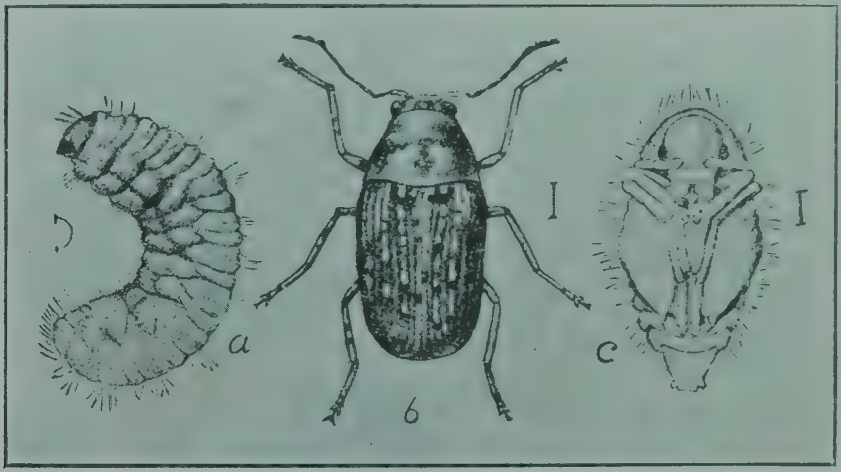

FIG. 16 —Coffee been weevil, *Aræocerus fasciculatus: a*, larva; *b*, beetle; *c*, pupa. (Copied from Chittenden).

"*Araeocerus fasciculatus* is a cosmopolitan insect living in the pods of various plants, among others in those of the coffee plant in Brazil, but is never known to attack healthy plants. The perfect weevil is also among the various insects which are mistaken by the planters for the Mexican cotton-boll weevil, but its very short and blunt beak should at once distinguish it from the latter species."

BENEFICIAL INSECTS.

The extraordinary multiplication of insects is counterbalanced in nature by the predatory or parasitic habits of species

of the same class. Just so, the presence of aphids and mealy bugs, which are both largely overproductive, on cotton here, attracts a large number of their natural enemies, many of which were introduced especially to check the ravages of these injurious forms. Among the beneficial species found in the cotton fields may be mentioned the well-known ladybirds or Coccinellid beetles. These differ slightly in their choice of food. *Cryptolaemus montrouzieri* and *Rhizobius ventralis* are known to feed on mealy-bugs; the following feed on aphids: *Coccinella repanda, Platyomus lividigaster, Scymnus notescens, Coccinella abdominalis* and *Scymnus vividus. Orcus chalybeus* feeds on the armored scale insects and *Chilocorus circumdatus* is a general scale insect feeder.

The larvae of Syrphid flies also feed on aphids and a familiar one about cotton is the larva of *Xanthogramma grandicornis* Macq. A much similar, though smaller, larva feeding on the cotton aphid is that of the Agromyzid fly, *Leucopis* sp. Four predaceous Hemiptera, *Zelus renardii, Hyalopeplus pellucidus, Triphleps persequens* (probably feeding on thrips) and *Rhopalus hyalinus,* have also been found on cotton feeding on aphids. These four have actually been taken in the cotton field; there are doubtless many more species that feed in a similar way on aphids.

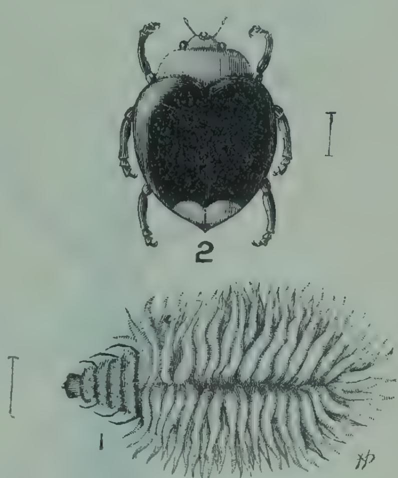

FIG. 17—*Cryptolæmus montrouzieri*, a predaceous species; 1, larva; 2, adult beetle. Nat. size indicated by line (Copied from Kirk.)

GENERAL CONSIDERATIONS.

The present report must be considered as preliminary only. The period of observation has been far too short to speak with much precision about the relative importance of the insects

now affecting cotton. Other pests will in all probability appear, both from among the native insects and from foreign lands. The vast importance of strict quarantine measures with regard to imported seed or other cotton stock is here emphasized.

With respect to the introduced pests of cotton, efforts to secure their natural enemies in the lands from which the pests have come are commendable. Resort to artificial methods, such as the use of insecticides, in combating cotton pests, has not been much advised, for practical reasons, but if their use should become necessary and it were shown that they could be used

FIG. 18—A predaceous bug, *Zelus renardii* Kolenati. (Copied from Swezey).

effectively, the question of practicality might disappear. In such contingency it is thought desirable to ascertain, as time permits, the relative effectiveness of various insecticides with respect to several of the more important pests.

The most promising field for improvement in conditions undoubtedly lies in cultural methods. In the United States the whole question of boll-weevil control, for instance, has practically resolved itself into the use of certain cultural methods. In all likelihood local problems will ultimately find solution in the utilization of similar devices.

Some stress might be laid on the value of a study of varieties with regard to the different degrees of susceptibility to insect attacks. Little has been done so far in this direction, but it deserves study in the future.

HAWAII AGRICULTURAL EXPERIMENT STATION
E. V. WILCOX, *Special Agent in Charge.*

BULLETIN NO. 19

EXPERIMENTS IN TAPPING CEARA RUBBER TREES

BY

E. V. WILCOX,
SPECIAL AGENT IN CHARGE OF HAWAII AGRICULTURAL EXPERIMENT STATION

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS.
U. S. Department of Agriculture.

HONOLULU:
PARADISE OF THE PACIFIC PRESS.
1910.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL

HAWAII AGRICULTURAL EXPERIMENT STATION,
HONOLULU, HAWAII, *Dec. 28, 1909.*

SIR: I have the honor to transmit herewith and recommend for publication, as Bulletin No. 19 of this station, a report on experiments in tapping Ceara rubber trees. The report embodies the results of one year's experiments, which were undertaken to demonstrate the yield of latex from Ceara rubber trees, and, therefore, the commercial prospects of the industry in Hawaii; and also the relative value of different methods and times of tapping, and the possibility of utilizing Japanese laborers, such as are found on the rubber plantations, in the work of tapping and collecting rubber.

The funds of this station during the year of the experiment were not sufficient to carry on the rubber investigations. The Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii therefore kindly consented to co-operate with the station, furnishing funds to the extent of $1,200.00, which, at the suggestion of Mr. R. S. Hosmer, Territorial Forester, were allotted from the funds which had been assigned to the Division of Forestry. The funds were assigned with the understanding that the work should be under the supervision of this station. All details of the plan of the experiments were worked out by myself, in consultation with Mr. Hosmer, and the actual work of tapping was done by Mr. Q. Q. Bradford and laborers under his direction. It is also a pleasure to acknowledge the active cooperation of the directors of the four rubber plantations on Maui in allowing the tapping of their trees and in furnishing the laborers and accommodations for the assistant who had direct charge of the work.

Respectfully, E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

EXPERIMENTS IN TAPPING CEARA RUBBER TREES.

INTRODUCTION.

The Ceara rubber tree has been grown in Hawaii in limited areas for fourteen years or more. It is only within the past four years, however, that commercial plantings of serious consequence have been undertaken. The chief rubber plantations at present are located on the island of Maui, but smaller plantings are found on Hawaii, Oahu, and Kauai. The area at present planted in rubber in the Territory is about 1,500 acres, of which about 1,300 acres are located on the windward side of Maui. The greater part of this area is planted in Ceara rubber, but there are also considerable plantings of Hevea and Castilloa. At present the new plantings which are being made are largely of Hevea rubber. Recently a few seed have been planted of *Manihot dichotoma* and *M. piauhiensis.* Limited numbers of *Ficus elastica, F. religiosa* and species of *Cryptostegia, Sapium, Kickxia, Calotropis,* and other genera of rubber trees are to be found in various localities.

While the Ceara rubber tree is considered as capable of thriving in a fairly dry climate, it has been found to grow much more vigorously where a generous rainfall is found, and the present rubber plantations are, therefore, located on the windward side of the various islands. With the change of opinion, which has recently been noted in nearly all rubber-growing countries, in favor of Hevea, as compared with Ceara rubber, most of the rubber plantations began to turn their attention more exclusively to Hevea, and some doubt was felt regarding the financial prospects from plantations of Ceara rubber. The experiments, which had previously been carried on in the Territory, and which were reported in Press Bulletin 13 and Bulletin 16 of this station, were necessarily on too

small a scale to allow of satisfactory conclusions as to the commercial importance of rubber in Hawaii. Occasionally, a doubt was expressed as to whether the location of these islands was not a little too far from the equator to insure any real success from rubber-growing.

Under the circumstances, it seemed necessary, particularly in view of the continued plantings which were being made, and the uncertainty of prospective yields, to undertake experiments which would shed light on the yield of latex to be expected from Ceara trees in the climate of the Hawaiian Islands, and on various other matters directly connected with the local conditions under which Hawaiian rubber plantations must operate.

THE YIELDS OF LATEX FROM YOUNG CEARA RUBBER TREES.

On account of the fact that rubber production is a new industry in the Territory, it is, of course, impossible to find large plantings of trees which are really old enough for commercial tapping. It is commonly recommended that trees should not be tapped until they are six to eight years old. There are only a few trees in the Territory of that age, and for purposes of comparison it is necessary to have a much larger number of trees. The majority of the trees tapped in the experiments reported in this bulletin were two or three years old. It was considered that the adaptability of Japanese labor to this work, and the actual time and expense of tapping trees and collecting rubber, could be determined on small trees, and that the yield which might be expected from mature trees could be determined with some certainty from the few large trees which are at present to be found in the Territory.

The first experiment was made in September, 1908, on 80 trees, averaging 13¼ inches in circumference at 3 feet from the ground. These trees averaged 23 feet in height and the branching began at about 10 feet from the ground. In this first series of 80 trees, which were tapped by means of 1 vertical cut each day, it required 36 hours and 40 minutes of labor to tap the trees, collect the latex, and secure, by coagulation, 1½ pounds of dry rubber. The trees were tapped by vertical cuts 7 feet in length, extending from the greatest height the laborers could reach, to a point near the ground. The cut was

made with a knife resembling an ordinary ferrier's knife, which removed a "v"-shaped strip of bark, extending nearly to the cambium. It was found somewhat difficult on new trees, with thin bark, to avoid injuring the cambium. This did not interfere with the flow of latex, but caused the healing scars to be irregular on many of the trees. The tapping was done at daylight, and the latex was collected as soon as the flow ceased. A spout, driven into the tree at the base of the cut, delivered the latex into the small pans, from which it was collected. On some days much difficulty was experienced in preventing the pans from being overflowed during excessively heavy rain storms. In this first series of trees it was found that four ordinary Japanese laborers could tap 80 trees in from 17 to 40 minutes. The men had never done any tapping previously, and required some instructions in the use of the knife and precautions to be observed. It required about two days for the laborers to become sufficiently expert to do the work without direct assistance and instructions. At the end of 15 days of tapping, they were able to tap a given number of trees in one-half the time which was required at the beginning.

In these, and the other experiments reported below, it was found that latex, unmixed with rain water, and in a thin layer in the bottom of the pan, would coagulate in about one-half hour. Latex, which remained attached to the side of the tapping wound was coagulated sufficiently for stripping off the scrap rubber, after one hour. When the latex was left at a depth of an inch or more in the pan, it sometimes required from one to two days for coagulation. The addition of water, either from rain or with deliberate intent, delayed coagulation considerably in every instance.

With regard to the economic handling of laborers in tapping rubber trees, it was found that the men could be kept at work for one-half day, at tapping and collecting, and that in the afternoon they could be utilized in washing rubber and utensils, or at cultivation or various other lines of work on the plantation.

In the second series of 160 trees, which were tapped with 2 vertical cuts, in the place of 1, it required only 40 hours of labor to tap the trees, collect the latex, and obtain 5 pounds of prime rubber and 2½ pounds of scrap rubber. With the present prices of rubber, it will be seen that when two vertical cuts were used daily profitable returns were obtained from

two-year-old trees. This result is encouraging when it is remembered that the labor of tapping the small trees is somewhat greater than that in tapping the large trees, and that the yield of latex is very much lower. With the same amount of labor, it is, therefore, possible to obtain a larger amount of rubber from mature trees. The small diameter of the trees, which did not average more than four inches, offered some mechanical difficulties in directing the knife so as to secure a reasonably straight cut. It is perfectly obvious, moreover, that a vertical cut in a tree of this small size, through a length of seven feet of the trunk, relieves the normal pressure inside the bark to such an extent that the flow of latex is continued for only a few minutes.

During these experiments it was found that one laborer can tap about 50 trees per hour, while another laborer can, in the same time, collect the latex from trees which would be tapped by two men. Since it appears, from subsequent experiments, which have been made in tapping mature Ceara rubber trees, that about one-third ounce of dry rubber may be expected as a daily yield from each tree, it is evident that three men should be able to obtain rubber from mature trees at the rate of about one pound per hour. The data, upon which this conclusion is based, have been carefully considered, and the estimate is probably not above that which may be normally expected. The rubber planters may, therefore, be reasonably assured that the Ceara rubber tree will not only grow and thrive in the Territory, but will yield profitable returns.

With trees four inches in diameter, it was found that the area of bark will allow tapping, with a single vertical cut daily, for two weeks in succession, or with two vertical cuts daily, for one week. In the case of larger trees, the tapping period may, of course, be much longer.

COMPARISON OF "V" CUTS WITH VERTICAL CUTS.

In October, 1908, 10 trees, averaging 25 inches in circumference, and of nearly mature age, were tapped for the purpose of comparing the yield obtained from "v" cuts and vertical cuts. The 10 trees were divided into 2 groups of 5 each, uniform in size and growth. The time required for making the two kinds of incisions was about the same in each case, being about 7 minutes for each group of 5 trees. The dry

rubber obtained from the 5 trees tapped with the "v" cut weighed 2⅛ ounces, and that from the 5 trees tapped with 2 vertical cuts weighed 6½ ounces. As was to be expected, the yield was much larger from the vertical cuts. This is in part, at least, due to the fact that the length of the incision is much greater with vertical cuts than with "v" cuts. The latex ran down to the pans somewhat more promptly from the vertical cuts, but the amount of scrap rubber left attached to the sides of the incisions was about the same in either case. Subsequent observations showed that the healing of the bark wounds took place about as soon in the case of vertical as in the case of "v" cuts, and the trunk ultimately became about equally smooth in either case. While the rate of flow downward, after issuing from the wound, was greater in the vertical cuts, the promptness and apparent pressure with which the latex issued from the wounds, was the same in both methods.

In November, 1908, 25 trees, averaging about 26 feet in height, and 20 inches in diameter, were tapped for 5 days in succession, making 14 vertical cuts 6 feet in length in the bark during this time. The purpose of this experiment was to determine whether there was any economy in using up all of the bark of the tree in a shorter time, by means of more cuts per day, than had been done in the previous experiments. The results indicated no advantage from the use of 4 vertical cuts daily, rather than 2. The amount of dry prime rubber obtained from 25 trees was 6.2 oz., and that of scrap rubber 6.1 oz.

As a further comparison of the yield from "v" cuts and vertical cuts, 8 trees on the station grounds, 14 inches in diameter, were tapped in December, 1908, 4 being tapped by either method. The results were again in favor of the vertical cut, whether or not a water-bag was used to wash the latex down into the pans and keep the wounds fresh. From the trees tapped with the "v" cut, 1.1 oz. of dry rubber was obtained, and those tapped with the vertical cut 0.9 oz.

TAPPING AT DIFFERENT HOURS OF THE DAY.

In November an experiment was carried out at Keanae, Maui, on 20 trees, averaging 15 inches, in circumference, five of the trees being tapped at 6 a. m., five at 8 a. m., five at 10 a. m., and five at noon. From a commercial standpoint, it is important to know how much time of each day may be profitably

devoted to tapping. If the tapping period were to be restricted to a few hours in the morning it would be a somewhat difficult matter to utilize the time of the laborers to advantage. The present experiment was, therefore, undertaken to determine the yield of latex at the four hours mentioned above. The weight of dry rubber obtained from tapping at 6 a. m. was 3.2 oz., at 8 a. m. 1.9 oz., at 10 a. m. 1.8 oz., and at noon 1.8 oz. From these results it is apparent that the yield is somewhat larger about daylight than at any subsequent time. The difference in yield, however, depends to a large extent on the climatic conditions. On clear days, with a bright sun, the flow of latex is much less after the sun is high in the sky than at daylight. On cloudy, cool days, on the other hand, the flow of latex is almost the same during any of the morning hours.

In order to gain additional evidence on the point in question, 30 trees, averaging 12 inches in circumference, were divided into three groups of 10 each, and were tapped at daylight, 10 a. m., and 1 p. m., respectively. In a period of one week 1.6 oz. dry rubber were obtained from the 10 trees tapped at daylight, 1.6 oz. from those tapped at 10 a. m., and 0.8 oz. from those tapped at 1 p. m. The weather was, on the whole, favorable to tapping quite late in the day. The conclusions which are to be drawn from these experiments, and other occasional tappings which we have made, indicate that, under ordinary conditions, it will be profitable to tap trees from daylight until nearly noon. On very hot, clear days, however, the later morning tappings may as well be omitted, or, in other words, the operation of tapping may, on such days, be better confined to the early morning hours.

Another experiment, to gain evidence on the importance of the time factor in the flow of latex, was carried out on Tantalus. In this test the yield from four trees tapped at 6 a. m. was 1.1 oz., at 8 a. m. 1.3 oz., at 10 a. m. 0.9 oz., and at 12 m., 0.3 oz.

THE USE OF WATER-BAGS TO WASH DOWN THE LATEX.

The openings of the latex tubes in the tapping wounds of Ceara rubber trees are sealed up within a few minutes, under ordinary conditions; and the flow stops. It was thought

advisable, therefore, to determine whether the wounds could be kept fresh and the length of flow increased by the use of a water-bag from which the water dripped slowly down the tapping wound. The results of this test indicate clearly that the yield may be somewhat increased by the use of the water-bag and the flow maintained for a somewhat longer time. The yields in one test were 0.8 oz. dry rubber with the use of the water-bag, and 0.5 oz. without. In the second test, 0.5 oz. with water, and 0.4 oz. without; and in the third test, which was made late in the day, 0.2 oz. with water, and .07 oz. without. While it appears certain, therefore, that the use of the water-bag will somewhat increase the yield, the economy of the operation is a matter which cannot be determined by experiments on a small number of trees, but only by making a test on a commercial scale when the rubber trees come to a mature age.

It was thought to be desirable to repeat the experiment with water-bags in another locality, the previous experiment having been carried out on Tantalus. The second test was made at Keanae, Maui, on 10 trees averaging 15 inches in circumference. In this experiment it was found that on hot, clear days the latex did not flow down to the pan on certain trees on which the water-bag was not attached. The yield, however, for the whole tapping period of two weeks, from the 5 trees on which water was used, was 3.5 oz., and from the 5 trees without water, 5.6 oz. This variation may possibly have been due in part to the unequal yielding power of the two sets of trees, but, at any rate, does not indicate any advantage from the use of the water-bag.

THE EFFECT OF NITRATE OF SODA UPON THE FLOW OF LATEX.

While fertilizers have been used in rubber plantations for increasing the growth and vigor of rubber trees, we have found no record of experiments to determine the possibility of increasing the flow of latex temporarily during the tapping period. It is apparent that if the flow can be considerably increased by the application of a quick-acting fertilizer, economy will be secured in the operations of tapping and collecting latex. The first experiment with nitrate of soda was carried out at Keanae, Maui, on Ceara rubber trees averaging 14 inches in circum-

ference. A uniform series of trees was found and divided into three groups which received one-half pound, one-fourth pound, and no nitrate of soda, respectively. Before applying the nitrate of soda, the yield of the whole group of trees was tested by means of uniform tapping. The weight of dry rubber from 3 trees, which received one-half pound of nitrate of soda each, was 2.3 oz.; from 3 trees, which received one-fourth pound of nitrate of soda, 1.3 oz.; and from the 3 unfertilized trees, 1.2 oz. The nitrate of soda was placed in the soil at a depth of three or four inches and at some distance from the trunk, around each tree, where it would most quickly become available to the roots. The weather was rainy during the experiment, which extended over a period of about two weeks, and the nitrate of soda was, therefore, rapidly dissolved and utilized by the tree, or washed away in the drainage water. The effect of the nitrate of soda upon the flow of latex was manifested within 48 hours.

A similar experiment was made on rubber trees growing on Tantalus, averaging about 12 inches in circumference. The soil about these trees was very loose and porous, and at the time when the nitrate of soda was applied, was unusually dry. After applying the nitrate of soda, the soil was thoroughly irrigated. The results from tapping these trees indicated that the nitrate of soda was almost entirely washed away by the heavy irrigation, so that little effect was noted in the amount of rubber obtained from trees to which the fertilizer had been applied. The flow of latex, was, however, in all cases, somewhat more vigorous from trees which had received nitrate of soda, and coagulation of the rubber from the latex took place more promptly. In a subsequent test, in the same locality, upon other trees, the yield of rubber was doubled by the application of one-half pound nitrate of soda per tree. In this case, the soil was moist at the time of the application of the fertilizer and no irrigation was applied during the experiment. Under ordinary conditions, on the windward side of the islands, the soil is sufficiently moist at all times to render the nitrate of soda promptly available.

The matter of the influence of nitrate of soda upon the flow of latex was considered sufficiently important to be put to a further test on rubber trees near the station office. These trees were about 11 inches in circumference. From one group of 5 trees 0.9 oz. of dry rubber was obtained in 3 days, before

applying the nitrate of soda, and 1.3 oz. from the same trees, in the three days following the application of the fertilizer. In this case, each tree received one-half pound nitrate of soda. On another group of 5 trees, the yield of rubber during the 3 days before the nitrate of soda was applied, was 0.9 oz., and during the three days following its application, 1.2 oz. It appears, from these experiments, that the flow of latex may be temporarily stimulated by applying nitrate of soda. It now remains for the planters to determine the exact economy of the method by applying it on a large scale as soon as rubber trees become mature.

RETAPPING TREES WHICH HAVE RECENTLY BEEN TAPPED.

The tapping wounds of Ceara rubber trees heal over promptly and smoothly if the operation of tapping has been done with ordinary care. Where the cuts have been made too deeply and have involved the cambium layer, the scar tissue is rough and furnishes some difficulty in subsequent tappings. This trouble, however, is less pronounced on mature trees than on young and rapidly growing trees. In order to determine the rate of flow from scar tissue of trees recently tapped, as compared with the flow from trees of similar age and size, not previously tapped, 20 trees were selected on Maui and divided into two groups of 10 each, one of which had been tapped four months previously, while the other had never been tapped. This test does not give a correct indication of the promptness with which trees recover from previous tappings, for the reason that the trees in question had been too deeply tapped before, and the healing wounds were too rough and irregular. Some of the latex, therefore, did not flow into the pans and was consequently lost. The yield from the 10 untapped trees, averaging 15 inches in circumference, was 4.1 oz. of dry rubber, as compared with 2.2 oz. of dry rubber from the 10 trees which had been tapped four months previously. From this experiment, and also from other occasional tappings which have been made, it appears probable that the Ceara rubber trees in Hawaii may be profitably tapped about three times annually.

YIELDS FROM NEARLY MATURE TREES.

As already indicated, the number of Ceara rubber trees, which have reached the age and size for commercial tapping

in Hawaii is very small. Such trees have occasionally been tapped to determine the yield of rubber per day, and the results from these isolated experiments are in essential agreement. They indicate a yield of about one-third ounce of dry rubber per day from 5-year-old trees. Mr. W. M. Giffard, of Honolulu, kindly had some careful tapping tests made of three 5-year-old trees on the Maunawili Ranch. The trees were first tapped for a period of twelve days to a height of three feet and eight inches from the ground. The average yield per tree in these experiments was one-fourth ounce of dry rubber daily. Subsequently, the same trees were again tapped above the previous tapping wounds, using the same method of nearly vertical cuts. The second test also extended over twelve days and gave an average yield per tree of one-third ounce dry rubber daily. These two experiments were in a locality where the average rainfall is about 100 inches per year.

THE DISTRIBUTION OF THE LATEX TUBES.

It was thought that a study of the course and distribution of the latex tubes in the different species of rubber trees might give a basis for the methods of tapping which would give the largest yields of latex. Attention was naturally given largely to the Ceara rubber tree for the reason that this is the only species grown on a commercial scale in Hawaii which has reached a size sufficient for tapping. It was soon found, however, that the lateral connections between the latex tubes in the bark of Ceara give an opportunity for the rapid outflow of latex. This was apparent, both from a microscopic examination of numerous sections from the bark and wood of Ceara rubber trees, and also from practical tapping experiments. As indicated above, the flow of latex appears to be as prompt and vigorous from a "v" cut, at an angle of 45 degrees, as from a vertical cut; but no more so. Throughout this bulletin vertical cuts have been spoken of, although they are not strictly vertical. The cuts are nearly vertical until they reach the base of the tree, where they are curved in to one point to the spout driven into the trunk at that place. In most of the experiments the vertical cuts have been so made as to gradually cover one-half of the tree, the first two cuts being farthest apart at opposite sides of the tree, and converging to a point below. Subsequent cuts are made in pairs inside of the first pair until

the bark of one-half the trunk is used up. The same process is then repeated on the other side of the tree. The fact that the flow from vertical cuts equals that from "v"-shaped cuts, at an angle of 45 degrees, indicates that the latex readily escapes from lateral connecting branches between the longitudinal trunks of the latex system.

The following notes were made in a microscopic examination of sections from different species of rubber trees growing on the station grounds: In *Kickxia*, the latex tubes are distributed chiefly just underneath the epidermis, immediately outside of the cabium, and in the outer part of the pith bordering the wood tissue. There are numerous strands of the latex system connecting the latex tubes in the outer and inner portions of the bark. The inner group of the bark latex tubes is separated from the cambium by merely a few layers of parenchymatous cells. In Hevea, the main latex system is in one belt, located about half way between the epidermis and the cambium. There are no latex tubes in the pith. In *Ficus*, the latex tubes are chiefly found in the bark near the cambium. In the young growth, however, they occur throughout the pith. In *Cryptostegia*, the latex tubes occur on either side of the cambium and very abundantly throughout the pith. In *Castilloa*, the main latex system is in the bark, but a few strands of latex tubes are located in the pith, immediately underneath the wood tissue. In Ceara rubber trees, the latex tubes are found almost exclusively in the bark outside of the cambium. In order to obtain a full yield of latex, therefore, it is unnecessary to injure the cambium. The large number of connecting tubes between the main longitudinal trunks is conspicuous in Ceara rubber trees and accounts for the ready flow of latex from tapping wounds in any direction.

INTER-CROPS IN RUBBER PLANTATIONS.

In view of the fact that no returns can be expected from rubber trees until they are 6 to 8 years old, it seems desirable to utilize the ground between the trees during their early growth. For this purpose, several crops are well suited. During the past year about 100 acres of corn were grown in young rubber plantations with good results. The yield varied from 35 to 40 bushels per acre, even where the annual rainfall was 240 inches. Soy beans and other legumes, as well as rice hay,

may also be grown under the same conditions. Such cultures not only furnish crops which are valuable for forage or for other purposes, but also make it necessary to cultivate the soil, which, in turn, is good for the rubber trees, and reduces the expense of weeding. The favorable results, which have already been obtained from inter-crops in rubber plantations, have induced the planters to arrange for still larger operations along this line during the coming year. The ground between the trees can be utilized for other crops for the first two or three years. The planting distance, which was first adopted for rubber trees, was too close; but there is now a tendency to plant the trees about twenty feet apart each way. This leaves plenty of room for the economic utilization of the soil for other crops.

CULTIVATION OF RUBBER PLANTATIONS.

As already indicated, the cultivation of the soil between rubber trees by the growing of inter-crops has been found beneficial to rubber trees. Where the practice of inter-cropping is not adopted, it is necessary, for the best results, that the soil be well cultivated. Formerly the opinion prevailed that rubber could be treated as a forest tree and that cultivation might be neglected. A comparison of cultivated and uncultivated rubber trees, however, shows that the rate of growth, particularly in the young trees, may be nearly doubled by cultivation. Cultivation will, therefore make it possible to bring the trees to a size suitable for tapping at least one year earlier than would otherwise be the case. The saving of one year is an important factor in commercial success with rubber. Wherever possible, the best results are secured from plowing the ground before planting, followed by cultivation during the growth of the trees. If no cultivation is practiced until the trees are two or three years old, it is necessary to proceed carefully, since otherwise the superficial roots might be badly injured. Where cultivation is practiced from the start, however, the roots are forced deeper into the soil and no injury results.

MARKET VALUE OF HAWAIIAN RUBBER.

It was, of course, highly desirable to get expert opinion on the commercial value of rubber produced in the Territory. For

this purpose, samples were sent to A. T. Morse and Company, of New York City, and Siegmund Robinow of Hamburg. The samples sent to A. T. Morse and Company were ordinary biscuits obtained in the tapping experiments. The report of this company follows:—

"This seems to us to be of the same general nature as rubber now coming from Ceylon and the Straits Settlements. This rubber has developed very materially the last few years and is now a regular article of commerce. The most of the trees or plants which were originally started in Ceylon and the Straits Settlements came from Ceara, so it would be presumed that the plant is much, if not exactly, the same as the ones you have in Hawaii. The market price of the rubber to-day is about $1.27 per lb., less the charges of say, a brokerage, banker's commission, etc., which would amount to about 2 per cent. It seems to us that this sample is a trifle softer than most of the rubber coming from Ceylon and the Straits Settlements, but we have no doubt but what it is the same general quality and that the people in Hawaii can produce the same results as the Ceylon and Straits Settlements."

The price of prime Para rubber, at the same date, was $1.31 per pound.

The samples sent to Siegmund Robinow included fine yellow biscuits, containing some bark and dirt, similar biscuits without impurities, mixed scraps, and fine rubber, prime rubber which had been kept on hand for one year, and ordinary scrap rubber stripped from the sides of the tapping wounds. The prices quoted by Siegmund Robinow varied from 80 cents per pound, for ordinary scrap rubber, to $1.31 per pound, for prime biscuits. The price for prime Para rubber, on the same date, was $1.36 per pound. These figures must be considered very satisfactory when it is remembered that the rubber in the submitted samples was obtained from 2- and 3-year-old trees. The rubber from young trees is known to contain more resin and protein than that from older trees, and it is, therefore, slightly less valuable.

CONCLUSIONS.

So far as can be judged from the experiments outlined above, it appears that Ceara rubber trees will grow in a satisfactory manner in numerous localities in the Territory, particularly on the windward side of the islands. The labor upon which the planters must depend can readily be trained to do the work of tapping and collecting the latex. The yields from young trees indicate that good profits will be obtained from

Ceara rubber trees as soon as they reach a suitable size and age. The most rapid and vigorous growth of Ceara trees can be brought about only by cultivation of the soil. In localities where the ground is too rough for general cultivation, thorough hand-cultivation should be carried on around the trees. In order to obtain returns from the plantations before the rubber trees come into bearing, it seems wise to grow inter-crops.

A general fertilizer experiment has been planned and will be put into operation during the coming season. The purpose of this experiment is to test the utility of various fertilizers in promoting the growth of rubber trees, and to gain further evidence of the economy of temporarily stimulating the flow of latex during the tapping period. During the coming season chemical investigations will also be made on the composition of latex and the crude rubber, with reference to the improvement of methods of coagulating the rubber so as to free it, as far as possible, from impurities.

HAWAII AGRICULTURAL EXPERIMENT STATION
E. V. WILCOX, *Special Agent in Charge.*

BULLETIN NO. 21.

A Study of the Composition of the Rice Plant

BY

W. P. KELLEY
AND
ALICE R. THOMPSON

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS.
U. S. Department of Agriculture.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL

HONOLULU, HAWAII, *April 5, 1910.*

SIR: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 21 of this station a manuscript on A Study of the Composition of the Rice Plant, by W. P. Kelley, chemist, and Alice R. Thompson, assistant chemist. The uncertainty which has prevailed regarding the time at which fertilizers should be applied to rice, in order to produce their maximum effects, indicates the practical importance of the investigations herein reported. The chemical work, which has extended over two crops of rice, has brought to light some remarkably concordant results which have a direct bearing upon agricultural practice, and have also afforded data of considerable scientific value in an understanding of the effect of fertilizers and the reaction of plants to their application.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

A STUDY OF THE COMPOSITION OF THE RICE PLANT

INTRODUCTION.

For a number of years the use of fertilizers has enlisted the attention of an increasing number of chemists, and while nearly all of the important economic crops have been studied, rice appears to have received but scant attention.[1] This is due perhaps to the fact that rice for the most part is grown in countries where scientific agriculture is little advanced. It is true, this crop is chiefly grown in the Orient under a system that has effectively maintained the fertility of the soil for centuries, but it is equally true that but little scientific study of its fertilization has been made. Rice is grown in Hawaii almost exclusively by the Chinese; and while some dry-land rice is cultivated, possibly 99 per cent of the entire crop is grown in submerged culture. Influenced by the practice of applying fertilizers to sugar-cane when it is some months old, as is done by the sugar planters here, and following a modification of the system of partial application of liquid organic manures to rice culture in the Orient, the Chinese here apply chemical fertilizers to the rice just before the panicles burst from the leaf-sheath.

The rice soils of Hawaii are extremely porous and in spite of every effort to puddle these soils, there is considerable seepage from the submerging waters. Most growers maintain a submergence of about three inches of water above the surface of the soil, but if for any reason the inflow is shut off for a period of twenty-four hours a large percentage, and in many instances all, of this water will have passed below the surface. It is, therefore, only natural that the grower with little or no knowledge of the ab-

[1] See Texas Sta. Bul. 82; Louisiana Stas. Bul. 77; South Carolina Sta. Bul. 59. Various publications relating to rice have been issued by the Japanese, some of which deal with the fertilization of this crop.

sorptive powers of soils should apply fertilizer at, or near, the time when it would seem most needed; and since it is grain, and not straw, that is wanted, the practice of late applications is the more easily understood. The custom simply involves the idea of feeding the plant at the time when it is considered to be most needed.

For several years this station has devoted some attention to the use of fertilizers for rice. In this work[1] it has already been shown that marked increases in the yields of straw and grain may be produced by the application of certain fertilizers. The fertilizer experiments previously made here have followed for the most part the usual plan employed in plat experiments. Various fertilizing substances have been applied and the economy of the application measured by the increased weight of the mature crop. Deductions concerning the deficiency of the soil as regards a given element are often drawn from similar observations and frequently from no other data. More and more, however, is it being recognized that for fertilizer investigations to be of the greatest value, other factors must be considered. The influence on absorption by growing plants brought about by the application of soluble fertilizers, the changes induced by such applications on the physics and biology of the soil, the chemical reactions thus set in motion, etc., are not fully understood. Therefore, it is important that we have a more fundamental investigation of these questions. It is not sufficient that the agricultural worker make applications of the already known principles for the benefit of farmers; he should also seek to better understand the questions involved.

Recognizing the economic importance of this crop and the need for scientific data regarding its fertilizer requirements, a series of plat experiments were begun on the rice trial grounds of this station in February, 1909. In addition to the influence on the total yields, it occurred to us that the composition of the plant at its various stages of growth might throw some light on the question of how a given fertilizer acts. Then a determination of the period in the development of the rice plant, during which the main portion of a given element is absorbed, is important as forming a scientific basis for the time of fertilizer appli-

[1] Hawaii Sta. Rpts., 1907, p. 67; 1908, p. 65.

cation. It is obvious that if the rice plant absorbs its potassium, for instance, previous to the flowering period, it is useless to apply this element at the time the Chinese usually make the application.

In order to guard against lateral movement of the fertilizers each plat was surrounded by low dykes, constructed of puddled soil and rendered practically impervious to the passage of water. The plats at one end bordered on an open flume from which, through narrow openings in the dykes, a slow stream of water was admitted to each plat. The amount of water thus admitted to a given plat was so regulated as to just equal the loss through evaporation, transpiration, seepage, etc., so that a constant submergence was maintained on all plats alike.

At the beginning of this investigation it was our intention to determine the minerals, nitrogen and the total carbohydrates in the plant at different periods of growth; but during the course of the work the rice was found to contain such large percentages of various carbohydrates, especially at certain periods in its development, that it was decided to also make a study of this point. This bulletin, therefore, deals with three phases of this subject, and will naturally fall into three parts, as follows:

1. A study of the composition of the rice plant as affected by fertilizers.
2. A study of the absorption of nutrients by the rice plant.
3. A study of the carbohydrates in the rice plant.

Description of Soil.

The uniformity of the plats used in this experiment had been determined by growing on them the same variety of rice without the use of fertilizers through two previous harvests, and the yields indicated that the soil throughout was extremely uniform. The soil is a coarse, stony loam, rather low in organic matter, neutral, and well drained. Both previous experiments and chemical analysis showed the soil to be well supplied with calcium.

The following table will show the mechanical structure and chemical composition of this soil:

COMPOSITION OF RICE SOIL.

Mechanical analysis.[1]	Per cent.	Chemical analysis.	Per cent.
Coarse gravel and stone	27.4	Organic matter	10.11
Fine gravel	18.2	Lime	1.60
Coarse sand	10.1	Phosphoric acid	.48
Medium sand	4.8	Potash	.35
Fine sand	3.6	Nitrogen	.25
Silt	2.9		
Clay and fine silt	33.0		

The ten one-fortieth acre plats of this experiment were treated as follows: Three plats were not fertilized, forming, therefore, checks; the remaining seven each received different fertilizers, using the single elements on some, on others various combinations. Nitrogen, derived from ammonium sulphate, was applied at the rate of 60 pounds per acre, phosphoric acid, from superphosphate, at the rate of 45 pounds of phosphoric acid per acre; and potash, from sulphate, at the rate of 60 pounds of potash per acre. No lime was applied, since previous tests failed to indicate its need. After thorough preparation, the soil was flooded and left partially submerged for several days, after which the fertilizers were applied to the wet soil on February 6, thoroughly mixed with the same by hand and then completely submerged with a very pure artesian water, in which condition it was maintained throughout the experiment, with the single exception of a period of about five days during the flowering period. The water at this time was shut off in order to hasten backward fruiting stems and insure uniformity in ripening.

The rice-growers in Hawaii do not plant their rice in the fields where it is to mature, but in seed beds, where it germinates and grows until from twenty to thirty days old; then it is transplanted in clumps of from three to five seedlings in rows about ten by ten inches apart. In this experiment carefully selected seedlings from Japanese seed were transplanted on February 11 in clumps of threes, at a uniform distance of 9 x 10 inches apart. It may not be without interest to call attention to the uniformity of this rice. In the first place, the seed was

[1] The mechanical analysis was made by F. G. Krauss.

selected stock from a strain of rice that had been systematically bred in Hawaii for a number of generations; and secondly, a further selection was made at the time of transplanting, thus largely eliminating plants of low vitality, and insuring a high degree of uniformity. It is believed that inherent variations were in this way very largely controlled.

At this point the authors desire to express their thanks to Mr. F. G. Krauss, agronomist at this station, for cooperation in this work. All the cultural part of the investigations was done under his direction, and many valuable suggestions offered from time to time. The planning of this investigation, the securing of the analytical samples, and the presentation of the results were done by the senior author; the analytical work, for the most part, by the junior author.

Description of Analytical Samples.

Ten clumps, that is, thirty plants, selected so as to fairly represent a given plat, and which had reached, as nearly as possible, the desired stage of development, were taken from each plat at three different periods in the growth of the rice. The first series were drawn on March 27, or 44 days from the time of transplanting. This was just previous to the formation of the flowers; the second on April 21, at the time of full flowering, 25 days after the first harvest; and the third on May 17, at the time of full maturity and normal harvest, 26 days after the second harvest. These samples were carefully uprooted in such a way as to secure the entire plant, roots and all. After removing all adhering soil, by thoroughly washing the roots in running water, the samples were taken to the laboratory, where they were separated into their botanical parts. The separation of the plants from the first harvest consisted in merely severing the roots from the above-ground portion. Rice on this soil tillers greatly, and many of the culms at this time had not formed a true stalk, therefore only two parts, namely, roots and vegetative portion, were separated.

At the second harvest the plants were subdivided into four parts—roots, stems, leaves, and panicles. The roots were severed from the above-ground portion, as in the previous harvest; the leaves were detached from the stem in such a way as to leave

the leaf-sheath around the stalk attached to the stem; and the panicles were detached at their point of union with the stalk. The third, or mature, harvest was separated into five parts—roots, stems, leaves, chaff, and grain, the only difference between the separation of the second and third harvests being a division of panicles into chaff and grain.

The samples, after thorough air-drying, were weighed, finely ground, and subjected to chemical analysis. The nitrogen was determined by the ordinary Kjeldahl method, the minerals by the official methods for the analysis of inorganic plant constituents,[1] the carbohydrates by hydrolysis with hydrochloric acid, as outlined for the determination of starch in the official methods for the analysis of foods and feeding stuffs.[2] The carbohydrates, as determined by this method, include the reducing sugars, sucrose, starch, the pentoses and possibly other occasionally occurring hydrolisable carbohydrates, and were calculated for convenience to starch. It should be borne in mind, however, that the fiber, or cellulose, is not included in this determination, and the use of this designation should not be construed to mean total carbohydrates. This determination was made largely because of the known high carbohydrate content of rice, and it was thought that possibly the information obtained in this way would be of interest. A separation of the several carbohydrates in the entire series of samples would have involved analytical work far beyond the scope of this investigation. This separation, however, was undertaken with the samples from one plat, the discussion of which is reserved for the final pages of this paper.

At maturity the entire plats were harvested, and the yields of straw and grain recorded. In this bulletin, however, the discussion will be confined very largely to the analytical samples. At present, the field experiments have been carried through two crops and the third is under way. It is hoped to present the practical side of this question after the harvest of the third crop, and possibly during the present year.

At the outset it was our intention to analyze the samples from an unfertilized and each fertilized plat, but on account of the large amount of analytical work involved it has not been possible

1 U. S. Dept. Agr., Bur. Chem. Bul. 107 (rev.), p. 21.
2 Loc. Cit., p. 53.

to complete all of these. Only four have been completed, namely an unfertilized plat, the mineral plat fertilized with phosphoric acid and potash; the nitrogen plat, which was fertilized with nitrogen only; and the complete fertilizer plat, which was fertilized with nitrogen, phosphoric acid, and potash. The primary reason for selecting these plats for analysis is found in the fact that nitrogen was the only element that materially influenced the growth of the rice. This fact manifested itself in the early development of the crop and was maintained throughout its growth. The weights of the entire plats at maturity failed to show that the application of any element, other than nitrogen, had materially affected the growth of the rice. It is unfortunate in this investigation that a soil somewhat deficient in other elements was not available.

A further reason for limiting this investigation to the four plats is found in the fact that the weather during a considerable portion of the growing period was extremely unfavorable for rice. The temperature was low for a longer time than usual and the rice consequently did not make normal growth. This fact, coupled with the almost universal practice in Hawaii of growing two crops of rice on the same land each year, suggested the advisability of studying both a spring and fall crop. Fortunately, the climatic conditions in the fall were strikingly different from the spring, and excellent weather conditions prevailed throughout the second crop.

The same procedure was followed with the fall crop as with that grown in the spring, the same fertilizers in like quantities being applied on July 16. The rice was transplanted on July 20, and the first series of samples drawn on August 26, the second on September 13, and the third on October 9. These samples represented stages of development as nearly corresponding to those from the spring crop as could be determined. At this point it is sufficient to merely call attention to the more rapid development of the rice in the fall than in the spring, ninety-five days from the time of transplanting being required for maturity in the spring, as contrasted with eighty-one days in the fall. In the table showing the gross weights at different periods it will be seen that much greater growth was also attained in the fall.

THE COMPOSITION OF RICE AS AFFECTED BY FERTILIZERS.

First Period, Spring Crop.

The results from the spring crop will be submitted first. The following table will show the water-free composition of the plant at the first harvest:

THE WATER-FREE COMPOSITION OF RICE JUST BEFORE THE FORMATION OF THE FLOWER

	CHECK PLAT			MINERAL PLAT			NITROGEN PLAT			COMPLETE FERTILIZER PLAT		
	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
itrogen	1.14	2.43	2.17	1.22	2.55	2.32	1.46	2.95	2.68	1.55	3.06	2.78
otash	1.86	2.51	2.38	1.97	2.28	2.22	2.02	2.96	2.80	2.40	3.11	2.97
hosphoric acid	1.10	.89	.93	.97	.81	.84	1.20	.98	1.02	1.65	1.19	1.28
ime	.44	.19	.24	.....	.....	.....	.....	.....	.....	.42	.24	.27
lagnesia	.51	.24	.29	.....	.....	.....	.....	.....	.....	.44	.19	.24
arbohydrates .	29.94	30.36	30.27	27.89	26.18	26.42	28.14	25.86	26.24	24.09	26.40	26.07

Nitrogen. The data show some unexpected and interesting facts. It is seen, for instance, that both the roots and vegetative portions from the plats fertilized with nitrogen contain a considerably higher percentage of nitrogen than from the plats not so treated. The application of minerals, in conjunction with nitrogen, also brought about a slightly greater absorption of nitrogen than the application of nitrogen alone; minerals alone increased the percentage of nitrogen somewhat, although by no means to so great an extent. Note the higher percentage of nitrogen in the dry matter of the above-ground portion of the plant, than in the roots, this being, in the case of the former, about double that of the latter.

Potash. The percentages of potash in the rice from different plats bear a similar ratio to that which was found to exist between the percentages of nitrogen, with the single exception of the mineral plat. It is significant that the application of minerals alone resulted in a slight depression, whereas the application of nitrogen alone increased the percentage of potash in the dry matter. As in the instance of nitrogen, the roots contain a smaller percentage of potash than the vegetative portion.

Phosphoric Acid. The percentages of phosphoric acid are found to have been influenced very similarly to potash, although not to such marked degree. Attention is called to the reduced percentage of phosphoric acid in the mineral plat. As contrasted with nitrogen and potash, the roots are found to contain a higher percentage of phosphoric acid than the above-ground portion.

Lime and Magnesia. Calcium and magnesium were determined in the samples from the unfertilized and complete fertilizer plats only; and the percentages were found to be very similar either when one plat was compared with the other, or calcium with magnesium. The roots contained about two times the percentage of each of these elements that was found in the vegetative portion.

Carbohydrates. The carbohydrates, as shown in the table, were also influenced by the fertilizers, the percentages in the different plats standing in inverse ratio to the percentages of nitrogen. The application of potash appears to bear no relation to the elaboration of carbohydrates up to this point.

Second Period, Spring Crop.

The following table shows the composition at the flowering period:

THE WATER-FREE COMPOSITION AT THE TIME OF FULL FLOWER

	CHECK PLAT					MINERAL PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.68	.63	1.80	1.45	1.15	.66	.60	1.72	1.50	1.12
Potash	.93	1.77	1.89	.72	1.49	1.01	1.65	1.84	.68	1.43
Phosphoric acid .	.91	.74	.63	.68	.71	.78	.69	.56	.60	.64
Lime	.42	.12	.36	.12	.22	.....	.....	.....	.....	.....
Magnesia	.39	.21	.20	.27	.24	.....	.....	.....	.....	.....
Carbohydrates ..	35.09	44.08	24.00	33.01	34.86	40.08	44.87	23.25	33.24	35.64

	NITROGEN PLAT					COMPLETE FERTILIZER PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.59	.61	1.69	1.45	1.08	.55	.63	1.63	1.30	1.05
Potash	1.05	1.81	2.00	.66	1.57	1.10	1.98	2.15	.72	1.74
Phosphoric acid .	.87	.74	.66	.64	.71	.86	.69	.65	.67	.69
Lime	.....	.....	.....	.....	.....	.35	.11	.43	.12	.24
Magnesia	.....	.....	.....	.....	.....	.47	.21	.34	.27	.29
Carbohydrates ..	34.55	43.47	20.70	34.42	34.22	36.72	43.97	21.90	31.66	34.14

Nitrogen. The composition of the plant at the second harvest is materially different from that of the first, and the marked differences found in the earlier stages of growth seem to have become equalized. Much greater growth had been made at this time on those plats that were treated with nitrogenous fertilizer; but the percentage of this element in the dry matter fails to reveal a corresponding influence.

Potash. The percentages of this element have been considerably reduced also; but the influence of the fertilizers is still manifested, although to a lesser degree than in the first period. Again the application of nitrogen alone enabled the plant to absorb a greater percentage of potash than when it was unfertilized, and if the minerals were applied, in addition to nitrogen, a still greater percentage of potash was taken up. The application of minerals alone had but little effect.

Phosphoric Acid. At this harvest the fertilizers seem to have exerted no material influence on the percentage of phosphoric acid in the dry matter.

Lime and Magnesia. The percentages of calcium and magnesium in the plants from the unfertilized and complete fertilizer plats were found to be practically the same.

Carbohydrates. The percentages of hydrolisable carbohydrates had considerably increased since the first harvest, and bear a somewhat inverse ratio to the percentages of nitrogen. This period represents a time of rapid growth and a consequent great elaboration of carbohydrates. The total weight of the plant at this period shows a development of about four times as much dry matter as had been formed at the first harvest. Hence, we should expect a smaller percentage of nitrogen and minerals, and a corresponding increase in carbohydrates. At this harvest the plant was in the midst of its most vital activity —the process of seed formation. It was storing up reserve materials and transforming carbohydrates into true starch. The analytical data show some interesting results.

Third Period, Mature Harvest, Spring Crop.

The following table shows the composition of the different plats at maturity:

THE WATER-FREE COMPOSITION AT MATURITY

	CHECK PLAT							MINERAL PLAT						
	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent.*	*Per cent*	*Per cent*	*Per ent*	*Per cent*	*Per cent*
Nitrogen	.63	.50	.86	.52	1.36	.58	.90	.63	.46	.86	.49	1.36	.57	.88
Potash	.58	2.18	1.30	.96	.39	1.69	1.10	.54	2.31	1.32	.98	.44	1.78	1.18
Phosphoric acid .	.76	.26	.28	.43	.98	.30	.61	.67	.23	.23	.30	.92	.24	.53
Lime	.70	.10	.69	.15	.02	.24	.19	.....	.....	.....	.....	.....	.....	.....
Magnesia	.83	.08	.21	.26	.27	.13	.24	.....	.....	.....	.....	.....	.....	.....
Carbohydrates ..	34.55	29.61	18.53	18.02	79.66	24.36	47.32	35.74	28.64	22.07	17.53	80.97	21.61	47.18

	NITROGEN PLAT							COMPLETE FERTILIZER PLAT						
	Roots	Stems	Leaves	Chaff.	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.62	.44	.81	.56	1.31	.60	.85	.52	.40	.67	.47	1.24	.49	.78
Potash	.64	2.32	1.17	1.00	.42	1.74	1.15	.64	2.68	1.22	.93	.41	1.89	1.24
Phosphoric acid .	.68	.25	.23	.41	.89	.27	.54	.77	.20	.25	.32	.92	.24	.53
Lime	.....	.....	.....	.....	.....	.....	.....	.65	.10	.61	.17	.02	.27	.20
Magnesia	.....	.....	.....	.....	.....	.....	.....	.80	.10	.23	.21	.25	.16	.24
Carbohydrates ..	35.52	28.60	21.16	16.49	83.52	24.15	47.75	31.12	25.42	19.04	16.95	83.80	21.82	46.20

Nitrogen. As was found at the second harvest, the fertilizers appear to have exerted little or no influence on the percentage of nitrogen in the mature plant. There are certain irregularities in the same parts of the plants from different plats, but when we consider either the straw, which is here used to include stems, leaves, and chaff, or the entire plant, the percentages of nitrogen are very similar, with the exception of the complete plat, which contained a slightly smaller percentage of nitrogen. It is somewhat difficult to explain this variation.

Potash. The percentage of potash in the mature plant is found to have been somewhat modified by fertilization. In the total plant from the different plats, for instance, the percentage of potash was as follows: Check plat 1.10 per cent, mineral plat 1.18 per cent, nitrogen plat 1.15 per cent, and complete fertilizer plat 1.24 per cent. Thus it is shown that the application of potash brought about an increase in the percentage of potash in the dry matter, either when the complete fertilizer plat is compared with the nitrogen plat, or the mineral plat with the check.

Phosphoric Acid. The percentages of phosphoric acid contained in the several parts of the mature plant do not appear to have been influenced by the fertilizers. The percentage in the whole plant was only slightly less than at the second harvest, whereas the percentage in the straw had been reduced by more than half.

Lime and Magnesia. The percentages of these substances in the mature plant are nearly equal, there being only .04 per cent more magnesia than lime. The percentages in the above-ground parts, however, are decidedly different, the leaves having been found to contain a much larger percentage of lime than the other parts, whereas the percentage of magnesia is about equal in leaves, chaff, and grain. Lime occurs in the grain to the extent of .02 per cent as contrasted with .24 per cent magnesia.

Carbohydrates. The carbohydrate data, while not altogether concordant, show that the process, already begun at the second harvest, was continued with acceleration. There is a general lowering of the percentage of carbohydrates in all the plant organs, except grain, where it is stored up. The fertilizers seem to have had little influence on this process, except in the grain

from the plats fertilized with nitrogen, which contain about 3 per cent more carbohydrates than from the other plats.

As already stated, the weather conditions during a large part of the growth of the spring crop were very unfavorable. Rice throughout the islands made unusually slow growth and small yields were obtained generally. It should be borne in mind, however, that there were no variations in moisture in the two respective crops, and therefore, the differences in the behavior of the plant may be safely attributed to temperature. The results from the fall crop will now be given.

First Period, Fall Crop.

The following table represents the composition of the plant at the first harvest from the fall-grown crop:

WATER-FREE COMPOSITION AT THE FIRST HARVEST

	CHECK PLAT			MINERAL PLAT			NITROGEN PLAT			COMPLETE FERTILIZER PLAT		
	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	1.07	2.16	1.99	1.00	2.10	1.95	1.28	2.30	2.17	1.48	2.72	2.50
Potash	2.06	3.12	2.96	1.97	3.08	2.93	1.90	3.25	3.07	2.50	3.51	3.33
Phosphoric acid	1.12	.92	.95	1.21	.83	.88	1.23	.84	.89	1.41	.90	.99
Carbohydrates	29.73	26.56	27.06	29.60	26.61	27.02	27.73	24.07	24.54	29.11	22.23	23.44

Nitrogen. The percentage of nitrogen in the dry matter was materially influenced by the application of this element, although the application of a complete fertilizer increased the percentage of nitrogen considerably more than the application of nitrogen alone. Minerals without nitrogen had but little effect.

Potash. The application of a complete fertilizer materially increased the percentage of potash in the dry matter. The application of minerals or nitrogen alone had but little influence on the percentage of potash during this period.

Phosphoric Acid. The absorption of phosphoric acid appears to have been influenced but slightly, if indeed at all, by fertilization.

Carbohydrates. The percentages of hydrolisable carbohydrates are found to stand in inverse proportions to the percentages of nitrogen in the dry matter.

Second Period, Fall Crop.

The following table sets forth the analytical data for the second period of the fall crop:

WATER-FREE COMPOSITION AT THE SECOND HARVEST

	CHECK PLAT					MINERAL PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.75	.65	1.72	1.28	1.01	.81	.74	1.46	1.32	1.02
Potash	1.18	2.02	2.33	.73	1.77	1.28	2.14	2.21	.77	1.81
Phosphoric acid .	1.02	.69	.49	.53	.64	.95	.68	.47	.59	.63
Carbohydrates ..	36.04	36.88	19.78	30.00	31.73	35.70	36.06	19.84	30.60	31.33

	NITROGEN PLAT					COMPLETE FERTILIZER PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.90	.89	1.64	1.41	1.19	.98	.81	1.63	1.38	1.15
Potash	1.50	2.45	2.12	.75	1.93	1.52	2.68	2.33	.79	2.12
Phosphoric acid .	1.06	.73	.41	.57	.63	1.23	.76	.45	.57	.67
Carbohydrates ..	32.24	29.59	18.43	31.41	27.40	33.40	30.80	18.82	29.52	27.64

Nitrogen. The previous fertilization with nitrogen exerted a direct influence on the composition of the plant at this harvest, the influence being most marked in the roots, stems, and panicles. As compared with the check plat the percentage of nitrogen in the total plant was increased by fertilization, as follows: .18 per cent by nitrogen only and .14 per cent by the complete fertilizer. Minerals alone exerted no influence.

Potash. The influence of the fertilizers on the percentages of potash absorbed is even more marked at this harvest than at the first. From all the fertilized plats there was a higher percentage of potash in the roots, stems, and total plant than from the check plat. This was much more marked in the instance of the complete plat, although nitrogen alone exerted an appreciable influence on this element. In the total plant, for instance, there is 1.77 per cent in the check plat, 1.81 per cent in the mineral plat, 1.93 per cent in the nitrogen plat, and 2.12 per cent in the complete fertilizer plat.

Phosphoric Acid. The use of fertilizers seems to have exerted but little influence on the percentage of phosphoric acid in the dry matter.

Carbohydrates. As was found in the first period, the hydrolisable carbohydrates stand in inverse proportion to the nitrogen assimilated. In the total plant, for instance, the nitrogen was as follows: 1.01 per cent in the check plat, 1.02 per cent in the mineral plat, 1.19 per cent in the nitrogen plat, and 1.15 per cent in the complete fertilizer plat; and carbohydrates in the corresponding plats, 31.73 per cent, 31.33 per cent, 27.40 per cent, and 27.64 per cent respectively.

Third or Mature Harvest, Fall Crop.

The composition of the plant at maturity was as follows:

THE WATER-FREE COMPOSITION AT MATURITY

	CHECK PLAT							MINERAL PLAT						
	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cen*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.76	.42	.61	.39	1.09	.46	.74	.72	.47	.65	.49	1.25	.52	.82
Potash	.71	2.44	1.26	1.02	.42	1.87	1.19	.70	2.20	1.18	.98	.46	1.69	1.16
Phosphoric acid .	1.15	.17	.17	.29	.86	.19	.52	.89	.18	.17	.31	.84	.21	.49
Carbohydrates ..	37.64	22.52	17.75	15.90	80.45	19.99	47.00	34.52	25.21	19.44	21.21	79.79	22.92	46.09

	NITROGEN PLAT							COMPLETE FERTILIZER PLAT						
	Roots	Stems	Leaves	Chaff.	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.84	.38	.62	.43	1.36	.45	.86	.71	.43	.56	.51	1.22	.48	.81
Potash	.73	2.62	1.33	1.06	.46	1.94	1.25	.94	3.06	1.29	1.12	.39	2.16	1.36
Phosphoric acid .	1.14	.14	.18	.26	.87	.18	.53	1.07	.15	.16	.32	.83	.19	.50
Carbohydrates ..	26.50	19.83	18.17	16.90	79.45	18.75	45.47	27.37	20.83	18.49	16.86	80.29	19.33	45.53

Nitrogen. The percentages of nitrogen in the different plats at the third harvest appear to have become very largely equalized. The straw contains practically the same percentage of nitrogen on all the plats, but the grain on each of the fertilized plats contained more nitrogen than on the check plat. Even the mineral plat shows this effect.

Potash. The percentages of potash in the mature plant show that the composition of the rice plant may be materially influenced by fertilizers. We find, for instance, that the potash in the straw varied according to fertilization as follows: The unfertilized plat 1.78 per cent, the mineral plat 1.61 per cent, the nitrogen plat 1.85 per cent, and the complete fertilizer plat 2.08 per cent. In the whole plant similar differences occurred.

Phosphoric Acid. The mature plant shows no appreciable differences in the percentages of phosphoric acid.

Carbohydrates. The percentages of carbohydrates show a fairly concordant agreement in all plats at maturity and only small variation occurred.

The Influence of Season on the Composition of Rice.

The temperature in Honolulu throughout the rice-growing months is usually very uniform, although somewhat warmer in the summer and fall than in the spring. During the first two months of the spring crop, however, the average temperature was lower than is usual for these months, whereas the temperature during the growth of the fall crop was normal.

The following table, taken from the reports of the U. S. Weather Bureau at Honolulu, shows the maximum, average, and minimum temperatures for each period of the two crops:

TEMPERATURE RECORDS.

	Spring Crop.			Fall Crop.		
	First period.	Second period.	Third period.	First period.	Second period.	Third period.
	° F.	° F.	° F.	° F.	° F.	° F.
Maximum ...	78	80	82	83	84	83
Average......	70.5	71	73	76.5	76.5	77
Minimum ...	56	62	67	68	68	70

These records show that the temperature was considerably lower during the growth of the spring crop, either from the standpoint of maximum, average, or minimum temperatures.

With the view of bringing out the difference in composition due to temperature, the following table, taken from the complete fertilizer plat, is brought together, which affords a comparison of the composition of the total plant when grown under the different seasonal conditions.

THE COMPOSITION OF SPRING AND FALL CROPS, TOTAL PLANT.

	First Period		Second Period.		Third Period.	
	Spring crop.	Fall crop.	Spring crop.	Fall crop.	Spring crop.	Fall crop.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen	2.78	2.50	1.05	1.15	.78	.81
Potash	2.97	3.33	1.74	2.12	1.24	1.36
Phosphoric acid	1.28	.99	.69	.67	.53	.50
Carbohydrates	26.07	23.44	34.14	27.64	46.20	45.53

These figures show that while the composition of the mature crop was not greatly influenced by season, at earlier periods it was markedly different. Considerably more nitrogen and phosphoric acid were absorbed for a given amount of dry matter in the spring crop, at the first harvest, than at the corresponding stage of development of the fall crop. At the second harvest these had become nearly equalized and at maturity were practically the same. With potash a somewhat different condition is found. The percentage of potash is consistently greater in the fall crop at every period than was found in the spring crop, although not greatly different at maturity. Considering the hydrolisable carbohydrates, the spring crop contained a much higher percentage at the first and second harvests than the fall crop. At maturity only a small difference is found, although there was a somewhat higher percentage in the spring crop than in the fall. It seems justifiable to conclude from the data, therefore, that seasonal variations are of importance, and must be considered in studying the composition of the rice plant.

General Discussion of the Results from Both Spring and Fall Crops.

Summing up the data for the two crops, it has been shown that the use of nitrogenous fertilizer produced a marked increase in the percentage of nitrogen in the dry matter during the early development of the plant. This increase, however, was not manifested throughout the life history of the plant, but extended only through the first period in the spring crop, whereas, in the fall crop a considerable increase in the percentage of nitrogen absorbed was still manifested at the second period. At maturity only slight differences were found. In both crops fertilization with minerals, in conjunction with nitrogen, brought about increased absorption of potash throughout the entire growth of the rice. Minerals alone tended to reduce the percentage of potash in the dry matter. The percentage of phosphoric acid in the dry matter was slightly increased by the fertilizers during the first period in both crops, being more marked in the spring crop. The second and third harvests, however, failed to reveal a similar influence on the composition.

The rice plant, in common with other cereals, contains a high percentage of nitrogen, potash, and phosphoric acid in its early growth, and these are gradually reduced until the time of maturity. The elaboration of carbohydrates proceeds at an increasing rate throughout the growth of the plant. It is found, for instance, that the total plant from the complete plat of the fall crop contained at the three periods the following percentages of these elements:

THE COMPOSITION OF THE RICE PLANT AT THREE DIFFERENT PERIODS OF GROWTH.

	Nitrogen.	Potash.	Phosphoric Acid.	Carbohydrates.
	Per cent.	Per cent.	Per cent.	Per cent.
First period	2.50	3.33	.99	23.44
Second period	1.15	2.12	.67	27.64
Third period	.81	1.36	.50	45.53

Calcium and magnesium, while determined in the spring crop only, show a slight concentration at the first period as compared with the percentages at later periods. In the mature plant the calcium is stored very largely in the leaves, while magnesium migrates to the grain.

THE ABSORPTION OF NUTRIENTS BY THE RICE PLANT.

As already stated, one of the objects in undertaking this investigation was to determine at what period in the growth of the rice plant the main portion of the several elements is taken up. The data and discussion presented in the preceding pages demand further development in order to throw more light on this point. It has been decided to present the complete data for the fall crop only, since this crop grew under more nearly normal seasonal conditions.

Dry Matter Formed. First, taking up the weights in pounds of dry matter per acre at the three periods, then the corresponding data for the several elements will be given. The following table shows the pounds per acre of dry matter in the several parts of the plant at the three periods:

AMOUNT PER ACRE OF DRY MATTER AT THE THREE PERIODS

	First Period			Second Period					Third Period					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Totsl Plant
	Lbs.	*Lbs*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs*
Check Plat	253	1382	1635	253	1686	723	660	3322	208	1616	659	639	2411	5533
Mineral Plat	203	1280	1483	255	1765	776	732	3528	276	1658	790	612	2199	5535
Nitrogen Plat	335	2256	2591	363	2695	1434	1294	5786	347	2362	1222	982	3783	8696
Complete Fertilizer Plat	430	2009	2439	385	2488	1380	1094	5347	313	2345	1235	996	3610	8499

Considering the weights at the three harvests, it is readily seen that the rice made a very much greater growth on the plats treated with nitrogenous fertilizer. The effects of the treatment could be seen in the early stages of growth and were manifested throughout. Minerals with or without nitrogen, as already stated, had but little effect.

Nitrogen. The following table will show the nitrogen as found in the different parts of the plant at the three harvests:

AMOUNT PER ACRE OF NITROGEN ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	2.7	29.9	32.6	1.9	10.9	12.4	8.4	33.6	1.6	6.8	4.0	2.5	26.2	41.1
Mineral Plat	2.0	26.9	28.9	2.1	13.0	11.3	9.6	36.0	1.9	7.7	5.2	3.0	27.6	45.4
Nitrogen Plat	4.3	52.0	56.3	3.3	23.9	23.5	18.3	69.0	2.9	8.9	7.5	4.2	51.4	74.9
Complete Fertilizer Plat	6.4	54.6	61.0	3.8	20.1	22.4	15.1	61.4	2.2	10.1	6.9	5.1	44.1	68.4

Considering the greatest amount of an element contained in the plant at any one time in its development as 100, the data from the first harvest show that the plant had taken up 89.2 per cent of its nitrogen in the case of the complete plat, 75.2 per cent on the nitrogen plat, 63.6 per cent on the mineral plat, and 79.3 per cent on the check plat; at the second harvest it had absorbed 89.6 per cent on the complete plat, 92.1 per cent on the nitrogen plat, 79.3 per cent on the mineral plat, and 81.7 per cent on the check plat. Therefore, it appears that, from the standpoint of the needs of the plant, the time to fertilize with nitrogen is before or during the early growth of the crop. By early application of nitrogen, not only is the nitrogen absorbed early, but much more vigorous growth and tillering brought about. Certainly the application of nitrogen at a time when the plant has already absorbed four-fifths of its nitrogen could not produce the greatest increase in growth. The rice plant, in common with other cereals, needs readily available nitrogen in abundance during its early development.

The data in the previous table bring out the facts of transmigration of nitrogen also. The absolute amount of nitrogen in the roots, for instance, gradually decreased from the first to the third harvest. It is also found that the grain at maturity contained about 60 per cent. of the nitrogen in the total plant, and that of this a large part had been derived from the stems and leaves, which, at the second harvest, were found to contain considerably more of this element than at maturity.

Potash. The potash absorbed at the three harvests is represented in the following table:

AMOUNT PER ACRE OF POTASH ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	5.2	43.1	48.3	3.0	34.1	16.9	4.8	58.8	1.5	39.4	8.3	6.5	10.0	65.7
Mineral Plat	4.0	39.4	43.4	3.2	37.8	17.2	5.6	63.8	1.9	36.5	9.3	6.1	10.2	64.0
Nitrogen Plat	6.3	73.3	79.6	5.5	65.9	30.4	9.7	111.5	2.5	61.9	16.2	10.5	17.3	108.4
Complete Fertilizer Plat.	10.8	70.4	81.2	5.8	66.7	32.2	8.7	113.4	2.9	71.8	15.9	11.2	14.1	115.9

The above table shows that the rice from the complete plat, at the first harvest, had absorbed 70.1 per cent of its maximum potash, from the nitrogen plat 71.4 per cent, from the mineral plat 67.9 per cent, and from the check plat 73.5 per cent. At the second harvest it had absorbed on the complete plat 97.8 per cent. on the nitrogen plat 100 per cent, on the mineral plat 99.7 per cent, and on the check plat 89.5 per cent of its total potash. The nitrogen plat seems to be an exception, in that it actually contained more potash at the second harvest than at maturity, there being only 97.2 per cent as much at maturity as at the previous harvest. Whether this apparent loss is due to analytical error,[1] it cannot be definitely stated. It is so slight, however, as to be of no great importance. The potash in the roots at the first harvest was gradually reduced throughout the subsequent growth of the plant, and at maturity the main portion of potash is stored in the stems.

Phosphoric Acid. The next table will show the amounts of phosphoric acid absorbed at the different harvests.

At the first harvest the complete plat had absorbed 57.6 per cent of its maximum phosphoric acid, the nitrogen plat 50.8 per cent. the mineral plat 47.9 per cent and the check plat 53.8 per cent. while at the second harvest the check plat contained 73.7 per cent, the mineral plat 81.7 per cent, the nitrogen plat 81.4 per cent, and the complete plat 85.7 per cent. The phosphoric acid in the roots at the first harvest was gradually reduced throughout the subsequent development of the plant, and during the period of seed formation a marked rearrangement takes place, resulting in the stems and leaves giving up practically all of their phosphoric acid, which is largely stored in the grain.

The foregoing data, therefore, reveal no scientific basis for the application of fertilizers to rice when it is two-thirds grown. By the time the plant has reached this period fully three-fourths of the total nitrogen and phosphoric acid and nine-tenths of the potash have already entered the plant; and hence the application of fertilizer at this time cannot possibly be of the greatest

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[1] Liebscher (*Jour. Landw.*, 35 (1887), p. 335), has pointed out that some plants sustain loss through the withering and decay of lower leaves. with rice grown in submerged culture, we believe such loss to be unimportant.

AMOUNT PER ACRE OF PHOSPHORIC ACID ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	2.8	12.7	15.5	2.6	11.6	3.5	3.5	21.2	2.5	2.7	1.1	1.9	20.6	28.8
Mineral Plat	2.5	10.6	13.1	2.4	12.0	3.6	4.3	22.3	2.5	3.0	1.4	1.9	18.5	27.3
Nitrogen Plat	4.1	18.8	22.9	3.9	19.6	5.8	7.4	36.7	4.0	3.3	2.2	2.6	33.0	45.1
Complete Fertilizer Plat.	6.1	18.1	24.2	4.8	18.8	6.2	6.2	36.0	3.3	3.6	1.9	3.2	30.9	42.0

value to the immediate crop, and is sure to result in a loss of plant food.

Hydrolisable carbohydrates. The following table will show the amounts of hydrolisable carbohydrates in the plant at its several stages of growth.

There is a rapid increase in carbohydrates from the first harvest till the last. At maturity there is less of these carbohydrates in the stems and leaves than at the second harvest. In addition to the transfer of these substances into the grain an enormous elaboration of true starch also takes place during the ripening process. This carbohydrate is, of course, very largely deposited in the grain. A fact worthy of notice in this connection is that there seems to be no relation between the absolute amounts of hydrolisable carbohydrates in the plant and the use of potash fertilizer. It is well known, however, that potash in some way not thoroughly understood is associated with the formation of the carbohydrates and their transference, and since in this soil there already existed a maximum of available potash it should not be expected that the application of this substance would produce appreciable effects on the amounts of carbohydrates in the plant.

Excessive Absorption. Numerous investigations have shown that the composition of mature plants may be very different, depending on the moisture supply, the amount of available plant food, the type of soil, seasonal variations, etc. Sugar beets grown on alkali soils are known to contain abnormal percentages of the alkalis present,[1] and this crop has even been grown on such soils as a means of effectively reducing the amounts of poisonous alkalis in the soil. Wheeler and Hartwell[2] have shown that a number of crops, when grown on certain soils and fertilized with sodium salts, take up less potash and more soda than when unfertilized. Voorhees and Lipman[3] have recently pointed out that the application of phosphates and potassium salts had the effect of reducing the percentage of nitrogen in corn, etc. They also found that the application of nitrogen from various sources, in addition to the minerals, tend-

1 California Sta. Bul. 128.
2 Rhode Island Sta. Rpt. 1906, p. 234.
3 New Jersey Stas. Bul. 221.

AMOUNT PER ACRE OF CARBOHYDRATES ELABORATED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	75.1	367.4	442.5	91.2	621.7	143.1	198.1	1054.1	78.5	363.9	116.9	101.6	1939.5	2600.4
Mineral Plat	60.0	340.8	400.8	91.1	636.3	154.0	224.1	1105.5	95.1	418.1	153.6	129.9	1754.4	2551.1
Nitrogen Plat	92.9	542.8	635.7	117.0	797.5	264.3	406.6	1585.4	92.0	468.5	221.9	166.0	3005.2	3953.6
Complete Fertilizer Plat.	125.3	446.5	571.8	128.7	766.2	259.6	323.1	1477.6	85.4	488.6	228.4	167.9	2898.8	3869.0

ed to bring about a higher percentage of nitrogen in the crop grown than was taken up when minerals alone were applied. Snyder[1] has shown that nitrogen fertilization may affect not only the total percentage of nitrogen in wheat, but he found this treatment to exert an influence on the form which the nitrogen assumed in the grain. Wiley[2] has shown that environment exercises a considerable influence on the composition of sugar beets, and recently Straughn and Church have brought out some interesting facts regarding variation in the sugar content of sweet corn,[3] due to climate, etc. Wiley[4] and McDonnell[5] show that the composition of rice grown in different localities varies considerably although sufficient data are not given to enable the reader to determine the causal factors.

The taking up of an increased percentage of an element per unit of dry matter formed under the influence of additional available plant food may be looked upon as excessive absorption, that is, more potash or nitrogen, as the case may be, is absorbed than is necessary for the elaboration of a given amount of dry matter. In fertilizer studies this fact is not only of scientific interest, but has a decided practical bearing. If an important function of fertilizers is to add necessary plant food to the soil, in the economic use of manures, it is important that every source of loss or waste be avoided.

The data already submitted are of interest in this connection. It has been pointed out that nitrogen is the only element that is materially deficient in the soil used in our experiment. This fact is brought out more strikingly by referring to the acre yields at maturity, which were calculated from the weights of the entire plats. These for both the spring and fall crops are submitted in the following table:

1 Minnesota Sta. Bul. 102.
2 U. S. Dpt. Agr., Bur. Chem. Buls. 95, 96.
3 U. S. Dpt. Agr., Bur. Chem. Bul. 127.
4 U. S. Dpt. Agr., Div. Chem. Bul. 45.
5 South Carolina Sta. Bul. 59.

AMOUNT PER ACRE OF AIR-DRIED GRAIN AND STRAW.

	Spring crop.			Fall crop.		
	Grain.	Straw.	Total.	Grain.	Straw.	Total.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Check Plat	944	1218	2162	2366	2525	4891
Mineral plat	1101	1478	2575	2174	2582	4756
Nitrogen plat	1683	2267	3950	3440	3816	7256
Complete fertilizer plat	1822	2578	4400	3354	3767	7121

The yields show that the minerals exerted a small influence on the gross weights of the spring crop. The fall crop grown on the same plats, and fertilized exactly as in the spring, however, yielded a smaller harvest where the minerals were applied, either when mineral fertilization is compared with no fertilization, or minerals and nitrogen with nitrogen alone. The differences in this particular are small in each crop, however, and are very likely within the range of experimental error. By referring to Table No. I, this soil is shown to contain a relatively high percentage of phosphoric acid, although we are quite aware that the deficiencies of a soil for a specific crop cannot with certainty be determined by chemical analysis. It has already been found that this soil contains .10 per cent phosphoric acid soluble in N|5 hydrochloric acid, and the potash in the coastwise soils of Hawaii is known to be quite soluble. We therefore feel justified in concluding that this soil contains an abundance of available minerals, and hence the application of minerals resulted in supplying to the rice an excess of available potash and phosphoric acid. What was the effect on the composition of the plant?

The percentage of phosphoric acid in the dry matter of the mature plant was found to have been unchanged regardless of the use of fertilizers, neither minerals nor nitrogen having produced any effect. The percentage of phosphoric acid absorbed during the first period was slightly increased by the application of phosphoric acid, only, however, when applied with nitrogen. In the case of potash, mineral fertilizers with nitrogen increased the percentage of potash in the plant throughout its growth. Minerals alone, on the other hand, did not so affect the plant. From these facts it seems reasonable to conclude that the rice

plant in the presence of an excess of potash may absorb an excess of potash. But with phosphoric acid we cannot be sure of a similar absorption. It seems most likely, however, that this soil already contained such a large amount of available phosphate as compared with that applied, that only a very temporary concentration was brought about, and that the rice on all plats alike had access to excessive amounts of phosphoric acid. Therefore, in this particular the data cannot be contrasted. All that can be said on this point is that analyses of rice, either straw or grain, grown on soil elsewhere[1] show an almost uniformly smaller percentage of phosphoric acid than we have found in Hawaii. The percentage of potash in the grain is also greater than has been found elsewhere.

We find that during the early stages of growth the rice on the plats fertilized with nitrogen took up nitrogen in excess over and above the maximum amount required for the production of a given amount of dry matter; and that in succeeding periods of its growth this nitrogen absorbed in excess was in part drawn on rather than that in the soil. For instance, during the first period one pound of nitrogen was absorbed for each 50 pounds of dry matter in the check plat, 51 pounds in the mineral plat, 44 pounds in the nitrogen plat, and 40 pounds in the complete fertilizer plat. At the second harvest one pound of nitrogen had been absorbed for each 99 pounds of dry matter in the check plat, 98 pounds in the mineral plat, 84 pounds in the nitrogen plat, and 83 pounds in the complete fertilizer plat; and at the third harvest one pound of nitrogen was sufficient for the formation of the following amounts of dry matter: Check plat 135 pounds, mineral plat 122, nitrogen plat 116, and complete fertilizer plat 123. Thus we see that one pound of nitrogen absorbed, was sufficient for the formation of more pounds of dry matter at all stages of growth on the check than on the plats treated with nitrogen. At the final harvest, however, this difference had become more nearly equalized.

If we consider, on the one hand, the growth during the third period only, which represents a time of rapid development and increase in weight, and the pounds of nitrogen absorbed during

[1] Texas Sta. Bul. 82; Col. of Agr. Tokyo Imp. Univ., Vol. 1, No. 12; South Carolina Sta. Bul. 59.

this period, on the other, we find that the plant when previously fertilized with nitrogen apparently drew in part on the nitrogen already stored up in the plant, rather than obtaining its nitrogen wholly from the soil. For instance, during this period one pound of nitrogen entered the plant from the soil for every 2?? pounds of dry matter produced on the check plat, 213 pounds on the mineral plat, 493 pounds on the nitrogen plat, and ??? pounds on the complete plat.

The Loss of Elements by Plants During the Ripening Stage. In recent years it has been pointed out that many plants contain a greater quantity of a given element at maturity than at some previous stage. In general, cereals have been found to contain their maximum of certain elements at the flowering stage, and in certain instances the absolute amounts rapidly decrease after passing through this stage. Wilfarth, Romer, and Wimmer[1] pointed out that both barley and wheat contained very considerably less potash and nitrogen at maturity than previously, and these authors attempt to explain this decrease on the assumption that these elements, after performing their physiological functions, are returned through the roots to the soil. Numerous investigations bearing on this point might be cited. Recently LeClerc and Breazeale[2] have investigated this subject, using a number of different crops, rice included, and from their work the conclusion is drawn that the loss of mineral constituents and nitrogen, which some plants suffer during the ripening process, cannot be explained on the basis of a backward and downward transmigration within the plant. They found, for instance, that the lower nodes of the mature wheat stalk contain less potash than the nodes higher up; and also that the roots contained rather less of this element at maturity than previously. On the other hand, when wheat, barley, rice, etc., are subjected to a leaching process, similar to natural rains and dews, a decided loss is sustained. From these findings they conclude that such losses in nature are due to the influences of rains and dews, which wash off and leach away the elements that are brought to the surface through transpiration, etc.

The data already submitted are instructive in this connec-

[1] Landw. Vers. Stat., 63 (1905), No. 1-2, pp. 1-70.
[2] U. S. Dpt. Agr., Yearbook 1908, p. 389.

tion. The rice from none of the plats, with the single exception of the nitrogen plat, and then only so slight as to be negligible, suffered any loss of minerals or nitrogen. It is true the plant had absorbed practically all its potash at the flowering period, but we find no evidence of a return to the soil. The percentages of nitrogen, potash, and phosphoric acid in the roots steadily decreased from the first period to maturity, which, as pointed out by LeClerc and Breazeale, would at least indicate the absence of a physiological process of excretion from root surfaces. The only abnormal weather condition to which the crop was subjected was the almost total absence of rain during the latter half of the growth. In addition, those who are familiar with weather conditions in Honolulu appreciate the fact that dews are exceedingly rare. It is the consensus of opinion of those who observed the weather during the time represented as the third priod in the growth of this rice, that not enough water fell or collected on this rice at any one time to trickle down the stalks. Hence there could have been no leaching, thus bringing about loss to the plant. From these facts it seems that rice grown under normal conditions does not return its elements through the roots to the soil; and, judging from the investigation cited, it seems most likely that leaching may be the chief means of loss to plants in this connection.

A STUDY OF THE CARBOHYDRATES IN THE RICE PLANT.

During the course of the work recorded in the preceding pages some parts of the rice plant were found to contain large amounts of the lower carbohydrates, and since various other carbohydrates, which undergo hydrolysis with boiling acids, are known to be present in mature cereals, it occurred to us that a study of the formation of these bodies might not be without interest. Accordingly, the samples from one plat were set aside for this work. The principal idea in this connection was, therefore, to gain further light on the various substances that are previously reported in this bulletin as carbohydrates. In addition, the cellulose (fibre) is also given. Attention is called to the fairly close agreement between the total of the various carbohydrates, as determined by the methods employed and "carbohy-

drates" previously given, which as already stated, were calculated to starch from the one determination, by the method of hydrolysis with boiling hydrochloric acid. The latter determination was not made with the samples reported herewith, however, and since certain variations were found in the plats already presented, it could not be expected that the sum of the carbohydrates, as determined separately, would be exactly equal to the lump determination, "carbohydrates", in any other plat. The more especially is this fact forced upon us when it is considered that the hydrolisable carbohydrates were previously calculated to starch, which is not only an arbitrary expedient, but cannot be looked upon as being mathematically correct, since, in hydrolysis different carbohydrates take up varying amounts of water and undergo changes of unequal magnitude. The agreement in the two instances is, therefore, as close as could be reasonably expected.

The carbohydrate groups which have been separated are as follows: Reducing sugars, sucrose, starch, pentoses, and cellulose. For the determination of reducing sugars the finely-ground samples were steeped with distilled water for a period of two hours, after which they were made up to a definite volume, filtered, and an aliquot taken for the regular Fehling solution reduction. Sucrose was determined by the process of inversion with invertase from yeast, and was likewise made up to a volume, filtered, and an aliquot taken for Fehling solution reduction. Starch was separated by first boiling the samples with water and then hydrolising with diastase from malt extract, completing to volume and filtering, after which an aliquot was boiled with hydrochloric acid to insure complete conversion into reducing sugars. After neutralization with potassium hydrate, the solution was allowed to act on Fehling solution. To all solutions alike, a small quantity of toluene was added to prevent alcoholic fermentation. In every instance the reduced copper was weighed as cuprous oxide. The pentoses were determined by the method of the Association of Official Agricultural Chemists, the phloroglucid being calculated to pentose sugars. The cellulose determinations were made according to the usual method for fiber determinations in feeds, etc.

First period. The following table sets forth the analytical results for the first period:

THE WATER-FREE CARBOHYDRATES AT THE FIRST PERIOD.

	Roots.	Vegetative portion.	Total plant.
	Per cent.	Per cent.	Per cent.
Reducing sugars	3.38	7.12	6.34
Sucrose	Trace	.00	Trace
Starch	8.51	8.13	8.21
Pentoses	22.09	12.02	14.09
Cellulose	26.02	19.97	21.20

Without discussing the data at length, it is sufficient to merely call attention to the rather large percentage of reducing sugars, especially in the above-ground portion of the plant, at this harvest. Sucrose was practically absent from the plant at this time, and starch occurred in almost equal percentages in all parts of the plant. There was a large percentage of pentose sugars, especially in the roots, being about twice as much in this part of the plant as in the vegetative portion. Cellulose also occurred in large quantities in the roots.

Second period. The following table shows the percentages of these substances at the flowering period:

THE WATER-FREE CARBOHYDRATES AT THE SECOND PERIOD.

	Roots.	Stems.	Leaves.	Panicles.	Total Plant.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Reducing sugars	5.23	6.53	2.92	.26	4.17
Sucrose	3.09	10.38	1.44	.00	5.01
Starch	11.15	13.44	4.00	9.54	9.63
Pentoses	19.25	14.31	16.51	20.03	17.18
Cellulose	23.74	22.57	24.29	33.18	28.30

The reducing sugars, as compared with the first period, were found to have been slightly increased in the roots and somewhat reduced in the above-ground portion, and were greatest in the stems. The panicles contained only .26 per cent of reducing sugars. The percentages of sucrose are indeed surprising, especially in the stems, where it occurred to the extent of 10.38 per

cent of the dry matter. In the panicles not a trace was detected. Starch had increased since the first harvest and was greatest in the stems, followed in order by the roots, panicles, and leaves. The percentages of pentoses were large in all parts of the plant, were greater than the percentages of starch in every part, and in the total plant almost double that of the latter. The percentage of fiber was still higher and varied somewhat according to the variations in pentose-forming bodies. In the total plant at this harvest cellulose constituted about one-fourth of its weight. The data are very interesting throughout and give an indication of the changes that take place as the plant proceeds in its development.

Third period. The next table shows the carbohydrates at maturity.

THE WATER-FREE CARBOHYDRATES[1] AT THE THIRD PERIOD.

	Roots.	Stems.	Leaves.	Chaff.	Grain.	Total Plant.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Reducing sugars	3.48	3.13	1.31	.54	.00	1.43
Sucrose	1.67	2.98	.88	.00	.00	1.12
Starch	9.55	9.36	3.79	2.42	79.08	33.75
Pentoses	19.51	20.81	18.44	18.41	1.82	12.98
Cellulose	25.77	30.13	22.67	37.84	.98	20.79

The reducing sugars, found at the previous period, are largely converted into higher carbohydrates in the mature plant, although appreciable quantities exist in all parts of the plant, save the grain, and are greatest in the roots. Sucrose, likewise, largely disappears, there being none in the chaff and grain. In the stems the largest per cent of this substance is found, although there is only about one-fourth as much as at the second period. There is a general reduction in the percentages of true starch in all parts of the plant, except the grain, where it is stored in large amounts. A somewhat higher percentage of pentose sugars is found in the stems at maturity than formerly, other parts of the plant being found to contain about the same amounts as at the second period. The grain contains only 1.82 per cent of

[1] The carbohydrates mentioned above obviously do not include all of the so-called nitrogen-free extract in the rice plant. An investigation of this matter will be taken up later.

these bodies. In the total plant the percentage of pentoses is considerably less than at the second harvest, although the total amount in absolute units had slightly increased. Cellulose accumulates in the greatest quantities in the stems and chaff; in other parts of the plant but little change has taken place since the previous harvest. Attention is called to the slightly reduced percentage of cellulose in the total plant, which, of course, is traceable to the great elaboration of starch during this period.

Summing up the data for the three periods, we found considerable quantities of reducing sugars in all parts of the plant, except the grain, at every stage of growth. The greatest concentration of these bodies was found in the vegetative portion of the plant during early growth, which were later partially converted into higher carbohydrates. Sucrose increased from a mere trace, at the first period to 10.38 per cent in the stems and 5.01 per cent in the total plant at the second harvest. At maturity the high percentages of sucrose, previously found, were also largely converted into higher carbohydrates. In the total plant, at the third period, only 1.12 per cent sucrose was found.

Starch gradually increased throughout the development of the plant, there being, in the total plant, 8.21 per cent at the first period, 9.63 per cent at the second, and 33.75 per cent at the third. This body is temporarily stored in the roots and stems at the second period, which reserve is later transported to the grain, probably by first being reconverted into soluble sugars, and then transformed again into insoluble starch in the grain through the intervention of the leucoplasts of the protoplasm. However the translocation is brought about, there is certainly abundant evidence that some such transformation takes place.

At the second period the forces in the plant are at their highest activity, which results in seed formation and the consequent storage of food material in the grain. The high percentage of sucrose in the stems at this period may be looked upon as being in the current which is carried by diffusion and osmosis from the chlorophyll-bearing cells to the grain, where it is to be later transformed into reserve material for the nourishment of the seedlings of the next generation.

The little-understood pentose-forming bodies are formed in

considerable quantities in the early development of the plant, and reach a practical maximum at the second period. The data show the large extent to which these bodies contribute toward the make-up of the carbohydrate content of the plant. Cellulose, the framework of the plant, had also almost reached its maximum at the second period, and, in general, bears a close relation to the percentages of pentoses formed.

SUMMARY.

1. Fertilization with nitrogen, either with or without minerals, greatly increased the growth of the rice at all periods of its development. Minerals alone, or in conjunction with nitrogen, slightly increased the growth in the spring crop, but in the fall a corresponding decrease attended this application.

2. The percentage of nitrogen in the dry matter, at the first harvest of each crop, was considerably increased by nitrogen fertilizer, and was still further increased by the application of minerals, in addition to nitrogen. The percentage of nitrogen in the mature plant was not materially changed by the fertilizers.

3. The dry matter from the plat fertilized with the complete fertilizer contained at every period of growth a higher percentage of potash than from the plats fertilized with nitrogen only. The application of minerals alone resulted in a decreased absorption of potash.

4. The percentage of phosphoric acid in the dry matter at the first period was influenced somewhat by the fertilizers. In subsequent growth no difference in the phosphoric acid content was found.

5. The percentages of calcium and magnesium in the total plant were not greatly different at the several periods of growth. The calcium at maturity is stored largely in the leaves, while magnesium migrates to the grain.

6. The hydrolisable carbohydrates vary inversely with the percentage of nitrogen absorbed.

7. The rice plant contains a high percentage of nitrogen, phosphoric acid and potash during early growth, which percentages become gradually reduced during later development.

8. Seasonal variations greatly influence the growth of rice, and likewise produce noteworthy differences in the composition, especially during early growth.

9. The rice plant, by the time it is two-thirds grown, has normally taken up about four-fifths of its maximum nitrogen and phosphoric acid and nine-tenths of its potash, and therefore fertilizers should be applied before planting or at an early period of development. In common with other cereals, rice demands readily available plant food in abundance during early growth.

10. Rice can take up what may be looked upon as an excess of nutrients if these be present in sufficiently large quantities.

11. There is no return to the soil through the roots of rice of nitrogen, phosphoric acid, or potash, and any loss of these substances that this plant may sustain is most likely traceable to the leaching action of rains and dews.

12. Reducing sugars were found in notable quantities in the rice plant at all stages of growth and were greatest at the first period.

13. Sucrose, while present as a trace at the first period, occurred in the stems at the second period to the extent of 10.38 per cent. At maturity this had been largely converted into starch.

14. Starch gradually increases throughout the growth of the plant and at maturity is stored very largely in the grain.

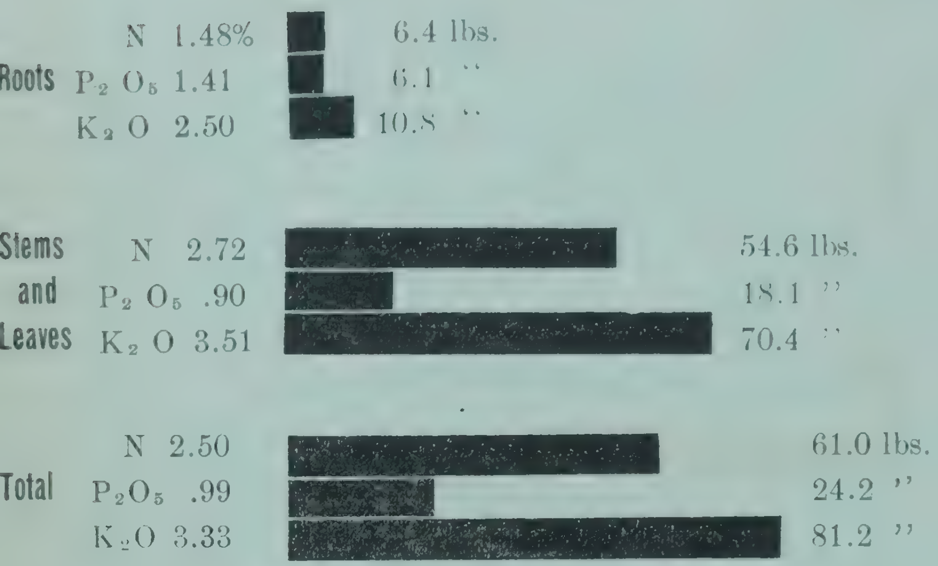
15. The pentose-forming bodies constitute a large percentage of the carbohydrates of the rice plant at every stage of growth and reach a practical maximum at the flowering stage.

16. Cellulose occurs in large quantities in all parts of the plant, except the grain, and likewise almost reaches a maximum at the second period.

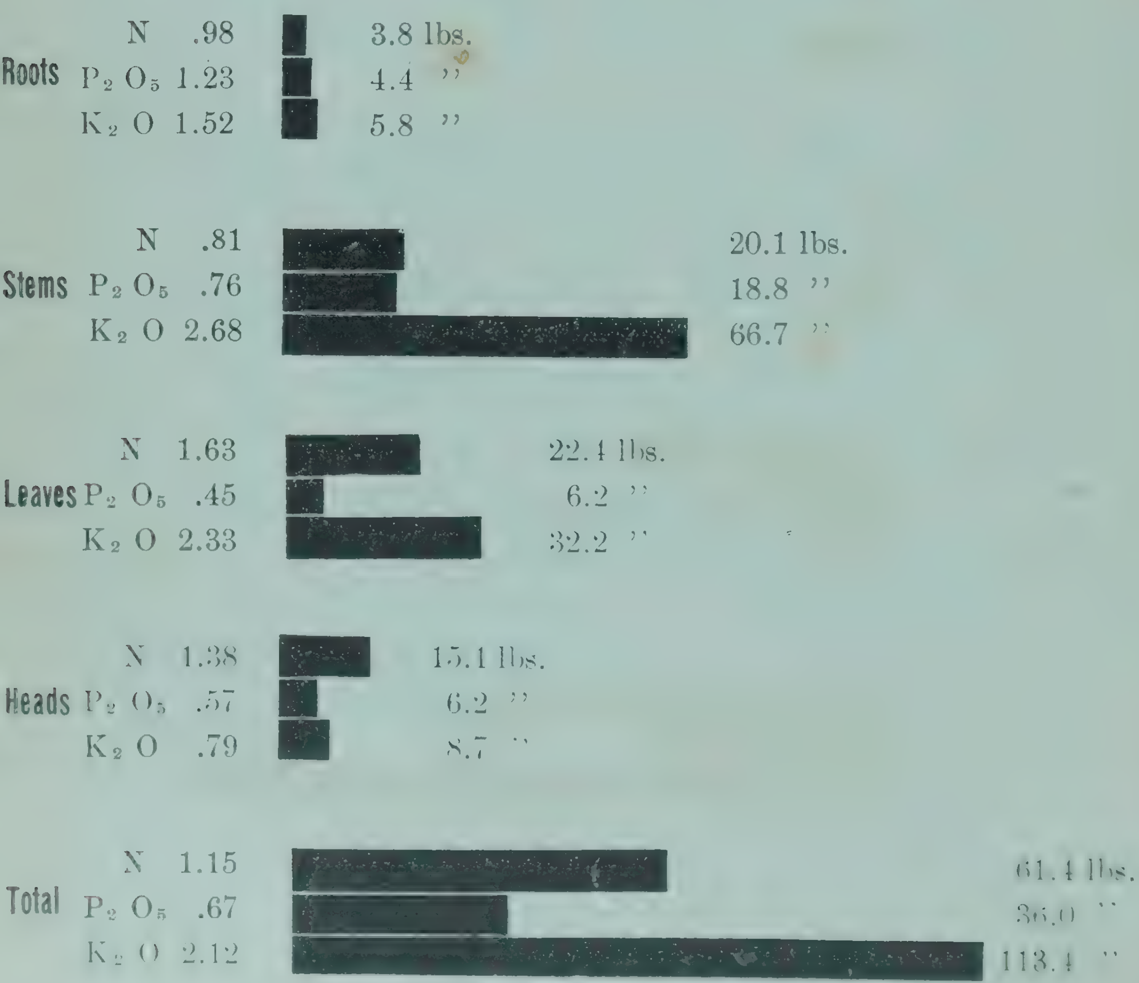
The above conclusions were drawn from a study of two different crops of rice and while the experiments are preliminary, the results should be considered as probable, though not definitely settled. In the near future the practical bearing of these experiments will be set forth in a publication of a more popular nature.

PLANT FOOD REMOVED BY RICE FROM ONE ACRE

First Harvest. (August 26, 1909).

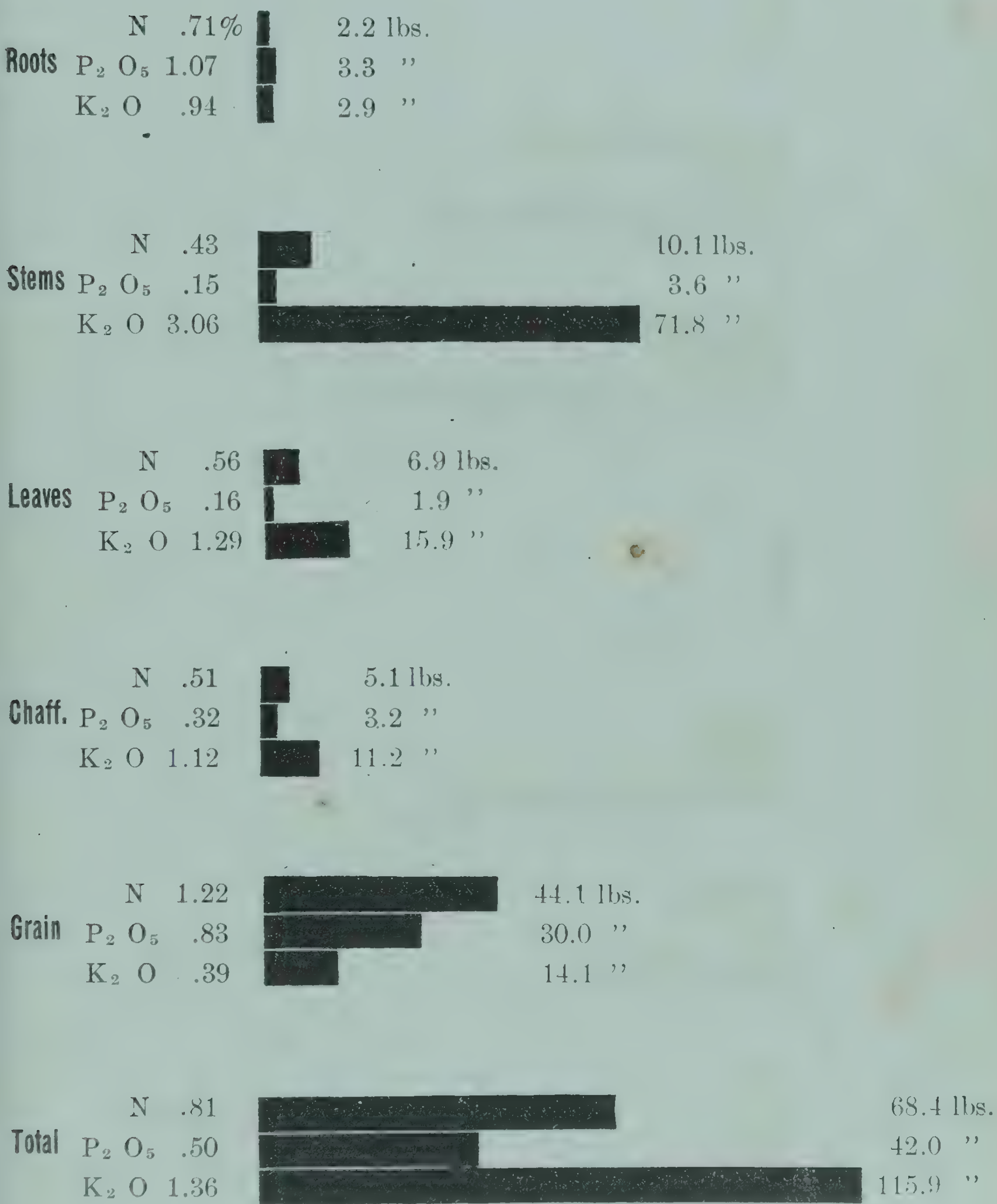


Second Harvest. (September 13, 1909).



PLANT FOOD REMOVED BY RICE FROM ONE ACRE

Third Harvest. (October 9, 1909)



Scale: 1 inch = 38.6 lbs.

HAWAII AGRICULTURAL EXPERIMENT STATION

E. V. WILCOX, *Special Agent in Charge.*

BULLETIN NO. 22

Insects Attacking the Sweet Potato in Hawaii

BY

DAVID T. FULLAWAY,

ENTOMOLOGIST

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS.

U. S. Department of Agriculture.

HONOLULU:

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[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL

HONOLULU, HAWAIIAN ISLANDS,
Dec. 27, 1910.

SIR:

I have the honor to transmit herewith and to recommend for publication as Bulletin No. 22 of this station a Report on the Insects Attacking the Sweet Potato in Hawaii, prepared by David T. Fullaway, entomologist. This report gives an account of the chief injurious insects of the sweet potato in the Hawaiian Islands, their life histories, habits, natural enemies, etc., and suggestions for their control. The sweet potato is one of the most important vegetables grown in the Territory and is cultivated everywhere in gardens and larger areas. On account of the fact that there is a constant market for this crop in Honolulu at a reasonable price and particularly on account of the fact that during the period from May 15 to July 15 a market is offered for sweet potatoes in San Francisco at a high price, it seems desirable to present an account of the insect troubles which growers are likely to meet, together with practical means of overcoming them. In order to assist the grower of sweet potatoes to identify the pests, a number of illustrations have been prepared and are believed to be necessary for a proper understanding of the text.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

LIST OF ILLUSTRATIONS.

INSECTS ATTACKING THE SWEET POTATO IN HAWAII.

INTRODUCTION.

The present paper, dealing with the insects which attack the sweet potato in Hawaii, was suggested by the very common use made of the sweet potato among the Hawaiians as an article of food, and its adaptability to cultivation by the homesteader, the small farmer, and other classes generally, on small patches of ground unsuited to general agriculture. While the sweet potato is not usually cultivated on extensive areas, the total acreage of this crop is undoubtedly large, and the present possibility of reaching coast markets when the sweet potato is out of season there, promises not only to extend its cultivation but to make a profitable industry out of what is now a rather uncertain agricultural pursuit.

A mere list of the insects attacking a crop is without much practical value. The aim, therefore, in this study has been to present all the information available in the case of each pest. This has involved much work on life histories, habits, natural enemies, means of control, etc.

The number and variety of the pests of the sweet potato may cause wonder as to how the plant persists until the potato is formed. While the depredations of the stem borer, which is an introduced pest and apparently without natural enemies, seem of a serious nature, the leaf eaters inflict no permanent injury on the plant owing to its prolific growth; and the destruction caused by the weevils which bore into the tuber can with proper measures be prevented. Potatoes of very fair quality are constantly being produced in spite of all insect damage.

The principal pests of the sweet potato are cutworms, sphinx, leaf miner, stem borer, leaf roller, and weevils.

CUTWORMS.

These attack a great variety of crops and when in excessive numbers inflict great damage. Of the 35 or more species of native and introduced cutworms and armyworms*, only eight have been observed commonly present and injurious to field crops, namely, *Cirphis unipuncta*, *Agrotis ypsilon* (Fig. 1), *A. crinigera*, *Feltia dislocata*, *Lycophotia margaritosa*, *Spodoptera mauritia*, *S. exigua*, *Caradrina reclusa*. The others are more or less confined to the mountains and kept in check by

FIG. 1—Cutworm and moth, *Agrotis ypsilon* Rott. Both twice nat. size. (Copied from Swezey)

parasites. Outbreaks of cutworms are more likely to occur in the cold and wet winter months than at other times of the year. They have never been observed by the entomologist on sweet potatoes, but they are reported to attack this crop at times. They are not easily suppressed when they get beyond the control of their parasites, and in one night may clean off all vegetation to the ground in the locality where they are present. Isolated individuals are especially troublesome to seedling plants or freshly planted cuttings. They are then controlled by distributing poisoned bait (white arsenic in moistened and sweetened bran) around the plants. The natural enemies of cutworms are

* O. H. Swezey, Armyworms and Cutworms on Sugar Cane in the Hawaiian Islands. Hawaiian Sugar Planters' Sta., Div. Ent., Bul. 7.

numerous and fairly efficient. The tachinid flies *Frontina archippivora* and *Chaetogaedia monticola*, the ichneumon *Ichneumon koebeli*, and birds are especially valuable.

THE SWEET POTATO SPHINX.

The sweet potato sphinx moth (*Protoparce convolvuli*) (Fig. 2) is practically a cosmopolitan insect. The larva—one of the "horn worms"—feeds on various species of Ipomœa. It is reported to be injurious to sweet potatoes in the United States, West Indies, Madeira and Canary Islands, Australia, and India. In Hawaii it often becomes destructive to wild Ipomœa vines, completely stripping the foliage, and is at times bad on sweet potatoes. The worm is usually found on the under side of the leaf, which it devours from the edge. A large worm will eat quite a few leaves during the course of a day and may eat some of the stem.

Life history. There are four distinct stages in the life cycle of this insect—namely, the egg, larva, pupa, and adult.

The egg. The eggs of the sphinx moth are laid singly on the under side of a leaf. Thirty or forty eggs, or even more, may be laid by a single moth. The egg is sub-spherical, smooth, shining, nearly colorless, with a greenish tinge, 1.35 mm. in diameter, finely punctured and firmly attached. The egg stage occupies from 6 to 8 days.

The larva. The larva when first hatched is about 3 mm.

FIG. 2—Sweet potato sphinx moth, *Protoparce convolvuli* (Linn.) nat. size. (Copied from Froggatt)

long, faintly greenish, almost white, with a black horn, the head pale greenish yellow. The entire larval stage covers about thirty-two days, in which time the worm increases in length to

115 mm. and proportionately in breadth. It molts four times and in the fifth larval instar has the characteristic and handsome appearance of the sweet potato worm. The color is very variable, and may be any shade of green or brown, from very light to very dark, almost black. The green form is thus described by Dyar*:

Head higher than wide, rounded, flat in front, smooth, shagreened; leaf green, with a broad, black, vertical band on each side covering the ocelli, which it just encloses by its well-defined anterior border; before it the ground color assumes a yellowish tint and preceding this yellowish shade is a faint, blackish clouded band; width 6 mm. Body plump and robust, the segments annulated; head slightly retracted below joint 2, and joint 2 below joint 3, but body elsewhere of uniform size. Horn large, tapering, curved backward, covered with short tubercles which bear very minute setae. Body smooth, colored leaf-green, a little mottled with whitish, with the following purplish brown mottled marks: a patch covering the thoracic feet and their bases; an oblique, subventral patch on joint 6 analogous to the marks covering the abdominal feet, each of which extends upward and forward obliquely in a broad band ending at the anterior border of the segment; the one covering the anal foot extends along subventrally to the anterior edge of joint 11; subanal plate green, contrasting with the nearly black bases of the feet, bordered above by a faint brown subdorsal shade; a broad, subdorsal band enlarged centrally on each segment, begins behind the cervical shield, widens and sends out an arm obliquely forward and downward on joints 5-11, each of which ends at the anterior edge of the segment before the spiracle. The band narrows on joint 11 posteriorly and ends at the horn, which is colored blackish brown with small greenish tip. The lateral branches of the subdorsal band are edged posteriorly with white, representing the usual oblique stripes; spiracles black, with a linear ochreous border and central dividing line, those on joints 5-12 surrounded by a circular black patch, contiguous (except on joint 12) to the oblique lateral lines. Length about 115 mm., of horn 7 mm.

When fully grown the larva usually contracts, lying on the surface of the ground or burying itself beneath the surface. The writer has not noticed that it constructs a cell. The larva ceases feeding perhaps five to six days before pupating. It is interesting to note that all the stages are shorter in Hawaii than in colder climates. Poulton† records the cycle from egg deposition to mature larva as occupying 61 days, while these stages cover a period of only 40 days in Honolulu.

The pupa. The pupa is stout, about 55 mm. long, and brown.

* Ent. News, 6 (1895), pp. 95-97.

† Trans. Ent. Soc. London, 1888, p. 550.

The tongue-case is quite long, extends away from the body and recurves about 22 mm. from its origin, the distal end lying on the body and forming the so-called "jug handle." The pupa is usually found in the ground. The pupal stage occupies 20 to 28 days.

The moth. The moth has the usual sphinx appearance, i.e., heavy body, large eyes, stout, narrow, pointed wings, thickened antennæ, stout, rounded abdomen tapering to a point, and is crepuscular in habit. It measures 45 mm. in length, 90 mm. in wing expanse, is of a generally dark gray color mottled with brown and black; the abdomen has a broad grayish brown dorsal stripe with short, transverse, whitish or pinkish bars on either side. The cheeks and venter are whitish, the antennæ grayish.

Remedies. When the sphinx moth caterpillars become a pest they may be controlled by hand picking or by the use of a poison to be sprayed on the foliage. Lead arsenate is perhaps the safest and most effective insecticide to use in this case. The species is kept in check by a hymenopterous fly, *Pentarthron semifuscatum* Perkins (Fig. 3), which parasitizes the egg. Dr. Perkins states that the larvæ are also decimated in the younger stages by parasites, presumably Echthromorpha and tachinid flies.

FIG. 3—*Pentarthron semifuscatum* Perk., parasitic on eggs of sweet potato sphinx. 55 x nat. size

THE SWEET POTATO LEAF MINER.

The genus Bedellia (Tineidæ) is represented in these islands by seven species, the larvæ in all cases being leaf miners. *B. somnulentella* and *B. minor* mine the leaves of species of Ipomœa, *B. oplismeniella*, leaves of a grass (*Oplismenus compositus*), *B. boehmeriella*, the leaves of *Boehmeria stipularis*. The host

plant of the other three species is not known except that the leaf miner commonly found in sweet potato leaves around Honolulu is, on the authority of Busck, *B. orchilella* (Fig. 4), and not the commoner *B. somnulentella* or *B. minor*. *B. orchilella* is not known outside of the Hawaiian Islands, *B. minor* is recorded from Florida and the Hawaiian Islands, and *B. somnulentella* has a wide distribution, occurring in Europe, the United States, Australia, New Zealand, Canary Islands, Madeira Islands, and Hawaiian Islands.

The injury is done by the larva or caterpillar, which soon after hatching penetrates the epidermis of the leaf and feeds on the mesophyl, the green tissue lying between the upper and lower epidermis. When small the caterpillar eats only the tissue in front of it, constructing a tunnel or mine as it proceeds. These tunnels are usually quite long and may be more or less straight, or cross and recross themselves, forming a complicated network. The mines or tunnels are plainly indicated by the discoloration of the leaf along their course. In its feeding a caterpillar may abandon one mine and begin another in a fresher

FIG. 4—Larva, pupa and moth, *Bedellia orchilella* Walsm. The larva is the sweet potato leaf-miner. 14 x nat. size.

portion of the leaf. While moving about on the surface from one location to another, they progress with a peculiar looping motion. When nearly mature the caterpillars eat the tissue all

around them, and not moving far away from the entrance to their burrow, the castings are ejected, forming small tufts of black excrementitious matter. They pupate externally, forming a characteristic case which is supported in a web, or fastened to the leaf by fine silken strands secreted by the larva prior to pupation.

When the leaf miner is abundantly present in a field, the plants usually have a seared or withered appearance, but are apparently not materially injured because of their rapid growth.

Life history. There are four distinct stages in the life cycle, namely, the egg, larva, pupa, and adult.

The egg. The eggs are laid singly, usually on the under side of a leaf, sometimes on the upper side, in a crevice alongside a leaf-vein. Apparently a number are laid by a single moth. The eggs are nearly white to reddish and highly iridescent, flattish, elliptical, .3 mm. by .2 mm., coarsely reticulate. The egg stage occupies about 8 days.

The larva. The larva when hatched is about .36 mm. long, pale green, head and cervical shield colorless, shining, segmentation distinct, setæ inconspicuous. The larva molts several times before attaining its full growth. When full grown it is about 7 mm. long, pale greenish, head, cervical shield and anal shield almost colorless, having a slightly brownish tint, the segmentation marked. Tubercles slightly fuscous, minute, each with a seta, arranged in longitudinal rows, (2) a little more removed than (1), (3) above spiracle, (4+5) below, (6) a trifle anterior, (7) ventral; spiracles concolorous. The larval stage occupies 10 days.

The pupa. The pupa is angular, 3.5 mm. long, dark green when first formed, turning to light brown with black spots and suffusions. Head with pointed projection in front black; horns and eyes black. Wing-cases extending to apex of ninth abdominal segment, third pair of legs a trifle further, antennæ to apex of tenth segment, all fuscous. Cremaster forked and armed with minute recurved spines, which are also found laterally on abdominal segments to sixth. A central longitudinal ridge on dorsum. The pupal stage occupies 6 days.

The moth. The moth is described as follows*:

Antennae brownish fuscous, with whitish annulations. Palpi, head and thorax greyish fuscous; face paler. Forewings greyish fuscous, with some pale cinereous speckling throughout; the only indication of markings is in the absence of the pale speckling at the base of the fold, in a slight spot on the outer half of the fold, and in a short dark streak on the dorsum, but these markings are very obscure; cilia pale greyish fuscous. *Exp. al.* 7 mm. Hind-wings dark grey; cilia fuscous. Legs greyish fuscous, with whitish tarsal speckling.

Remedies. It would be difficult to control the leaf miner by artificial means, such as the application of a poisonous mixture to the leaves, as the larvæ feed within the leaf, not on the surface. The arsenical sprays applied for other leaf-feeders, however, might contribute to lessen the infestation of leaf miner. Leaf miners are fairly well kept in check by the chalcid *Omphale metallicus* (Fig. 5), which parasitizes the larva. Another eulophid (*Pediobius*) has been bred from leaf-miner material and may be either secondary or primary.

FIG. 5—*Omphale metallicus* Ashm., parasitic on sweet potato leaf-miner. 30 x nat. size.

THE SWEET POTATO STEM BORER.

The sweet potato stem borer (*Omphisa anastomosalis*) (Fig. 6) is not a native insect but apparently a recent introduction from China. Its habitat as given by Hampson is China, Sikhim, Khasia, Nilgiris, Ceylon, Burma, Andamans, Java, Duke of York Island, and it evidently belongs to the Indo-Malayan region. It was first observed in Hawaii about 1900. Since then it has been increasing, and promises to be a serious pest if it is not checked by natural enemies.

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* Walsingham, Microlepidoptera. Fauna Hawaiiensis, vol. I, pt. 5, p. 725. Cambridge, 1907.

The injury results from the larva or caterpillar's boring the stems of the plants, causing them ultimately to wilt and die. Full-grown caterpillars are usually found near the base of the stem with a long tunnel behind them. The thick mass of decayed stems beneath the verdant foliage of the sweet potato is largely the result of the stem borer's work. The borers sometimes get into the potato, in which case the damage is even more serious.

Life history. There are four stages in the life cycle, as with the other moths—the egg, the larva or borer, pupa, and adult.

The egg. The eggs are laid singly or two or three together, usually in the crevices on the stems, sometimes on the leaves. They are elliptical (sometimes irregular), flat or moderately rounded, measuring .63×.50×.35 mm., pale green, finely reticulated on both surfaces. They hatch within 5 to 6 days of deposition.

The larva. The larva just after hatching is 1 mm. long, sordid white (the contents of the alimentary tract green beneath), head bilobed, black, and a black shield-shaped marking on cervical shield. Hairs conspicuous. Soon after hatching, the larva bores into the stem, a small tuft of ejected material indicating the point of entrance. The larval stage occupies 27 to 30 days, in the course of which several moults are undergone. The full-grown caterpillar is described by Swezey* as follows: "Length about 30 mm., width about 3½ mm., head 2 mm., color pale yellowish white, with conspicuous brown, very broad and flat tubercles; head yellowish brown, ocelli black except the two upper and the lowest one, which are white, mandibles black, a black line on postero-lateral margin of head; dorsal tubercles of two rows beginning with segment three, in each row, two per segment except segment four; a row of tiny tubercles, one per segment, just antero-ventral to each of the anterior dorsal tubercles in segments five to twelve; the spiracles of segments five to twelve have a group of four tubercles surrounding each; by their union on some segments there are but three of these; a similar cluster of tubercles occupies the position corresponding to spiracle on segments three and four; a

* Proc. Hawaiian Ent. Soc., 1 (1906), pt. 2, p. 76.

line of tubercles just dorsal of the base of the feet; four ventral tubercles on segments 5, 6, 11, 12 (those segments having no feet); the ventral tubercles have two or three hairs, others mostly but one, a few hairs on the head also."

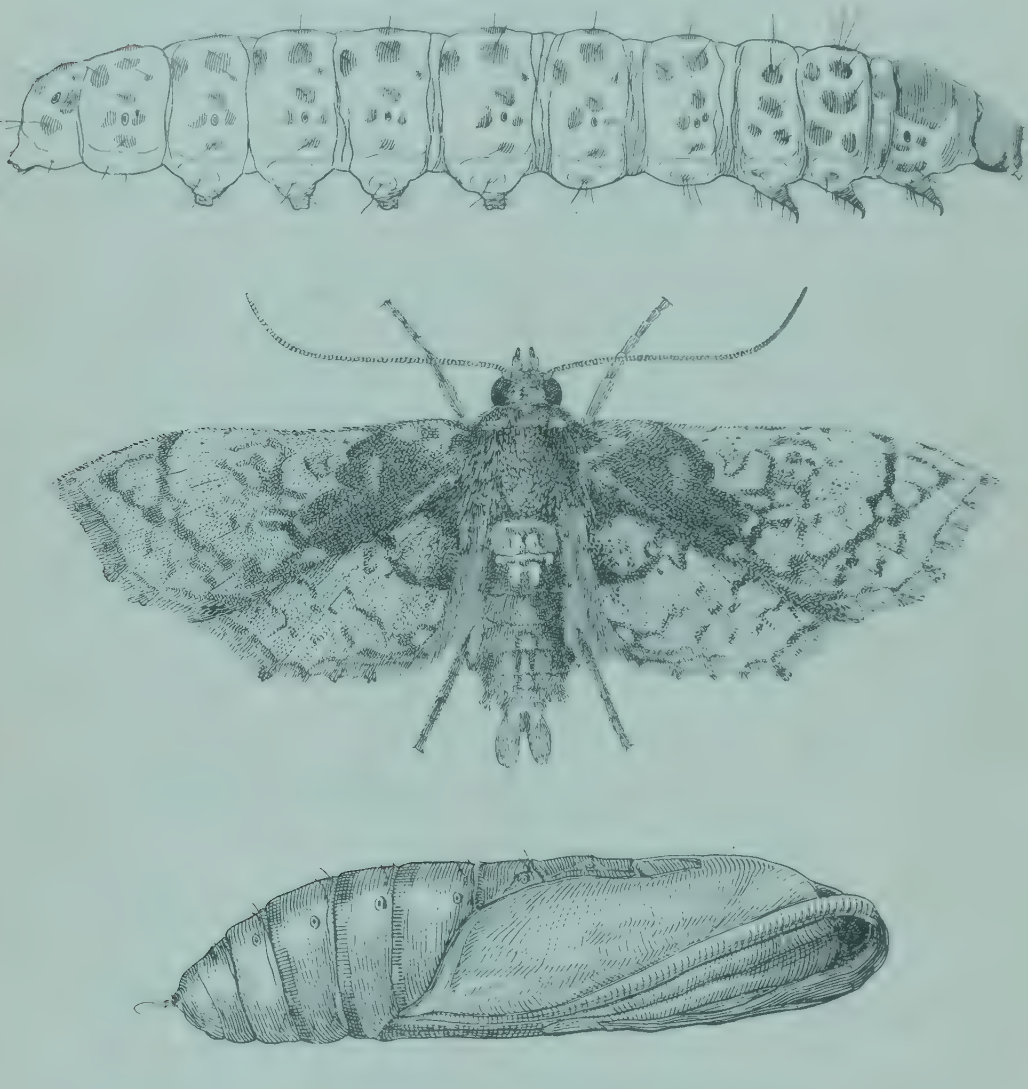

FIG. 6—Larva, pupa and moth, *Omphisa anastomosalis* Guen. The larva is the sweet potato stem-borer. 3 x nat. size.

The pupa. Pupation takes place in the stem near an exit from the burrow. The pupa is found in a slender web-like cocoon. It is described as follows: "16 mm. long and 3 mm. wide, nearly cylindrical, abruptly tapering at the two posterior segments; uniform medium brown, a slightly darker band on posterior margin of abdominal segments; tiny short hairs where

there were hairs on the larva; wing-cases a little pointed, extending to posterior margin of fourth abdominal segment, one pair of leg-cases extends a little farther, about half-way on the fifth segment; cremaster very short, blunt, with a few hooked spines." The pupal period is 16 to 18 days.

The adult. The following is a description of the moth*:

White, the head, thorax, and abdomen suffused with ochreous and rufous, leaving some paired pale spots on dorsum. Forewings with rufous suffusion on basal area extending below median nervure to middle of wing; hyaline patches at middle and end of cell, with a rufous-edged ochreous spot between them; a large rufous-edged ochreous patch beyond the cell; the outer area more or less irrorated and suffused with rufous; the veins rufous; a curved postmedial rufous line with an irregularly dentate line beyond it enclosing a series of hyaline patches; a marginal rufous line. Hind-wing with the base rufous; a dark-edged rufous irregular discocellular mark with line from it to inner margin; the outer area irrorated with rufous; two irregularly waved rufous post-medial lines; the apex, anal angle, and a marginal line rufous. Expanse 32-36 millim.

The moth is rather sluggish and slow to take the wing.

Remedies. No very effective remedy can be suggested for the stem borer, as most of the life of the insect is passed within the stem. The freshly hatched larvæ might be reached with an arsenical poison, and the moths can be trapped. Where sweet potato fields become badly infested, so that the crop becomes unprofitable, moving to a new location would seem to be the most practical course to pursue. An ichneumon fly, *Pristomerus sp.,* has been bred from the larva, but to what extent it parasitizes the stem borer is not known.

THE SWEET POTATO LEAF ROLLER.

The sweet potato leaf roller (*Phlyctaenia despecta*) (Fig. 7) has only recently been observed to attack sweet potato plants, although it is common in the mountains on wild species of the genus Ipomœa. It is evidently an indigenous insect that is accommodating itself more or less to the conditions under which the cultivated species are grown. It occurs on all the islands.

The larva or caterpillars of all the Phlyctænias are leaf rollers or feed in a depression or groove of a leaf beneath a web.

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* Hampson, Moths. Fauna British India, vol. 4, p. 382 (fig. 207). London, 1896.

Those of *P. despecta* feed on the under side of leaves, eating through to the epidermis of the upper surface, and their castings are scattered about in the filmy texture of the web. The young caterpillars move about in feeding, making a number of small abrasions. Maturer larvæ feed over a continuous surface, and when they are at all numerous they leave the foliage badly skeletonized.

Life history. There are, again, four stages in the life cycle—the egg, larva, pupa, and adult.

The egg. The eggs are laid singly on the upper surface of leaves, usually beside a vein. They are oval, flattish, about .65 mm. × .45 mm., greenish, iridescent, and finely reticulated. The egg stage covers about 8 days.

The larva. The larva when first hatched is about 2 mm. long, very pale (the contents of the alimentary tract green beneath), mandibles brownish. There are no visible markings, but the hairs are conspicuous. In the course of its growth the larva molts three or four times. The full-grown caterpillar is described by Blackburn as follows*: "Convex, broad in the middle and much narrowed at the ends; each segment individually also narrowed behind and in front; green, almost concolorous, save that the dorsal line is darker; a few long hairs on each segment." This description could be amplified as follows: Length 17 mm., head rounded, faintly bilobed and with cervical shield pale, mandibles and tips of antennæ brownish; on either side of dark green dorsal vessel an irregular white longitudinal line, due to the reflection of light from the opaque fat body; a few black spots on head and cervical shield as follows: on head, two, close to median margin of the lobe, one near posterior border, the other about half-way down face, a large one on lateral margin dorso-ventrally about midway between the other two; close to and slightly back of it a group of four minute spots; below it the ocelli, the lower three of which are bordered with black; on cervical shield four small spots in a longitudinal line on the dorsum somewhat removed from median line—sometimes coalesced in groups of two; tubercles of moderate size, sub-circular, somewhat convex, con-

* Ent. Mo. Mag., 19 (1882), p. 56.

colorous with body, each bearing a seta (sometimes two), arranged more or less in longitudinal rows on each side of the body as follows: on dorsum a row (1+2) a little removed from the median line—on segments 5 to 12 two per segment, the anterior (1) near anterior margin, the posterior (2) at about center of segment—on segments 3 and 4 (1) is ventrad of (2) and both are double tubercles; a row just above the spiracles (3); a row of double tubercles just beneath the spiracles (4)—

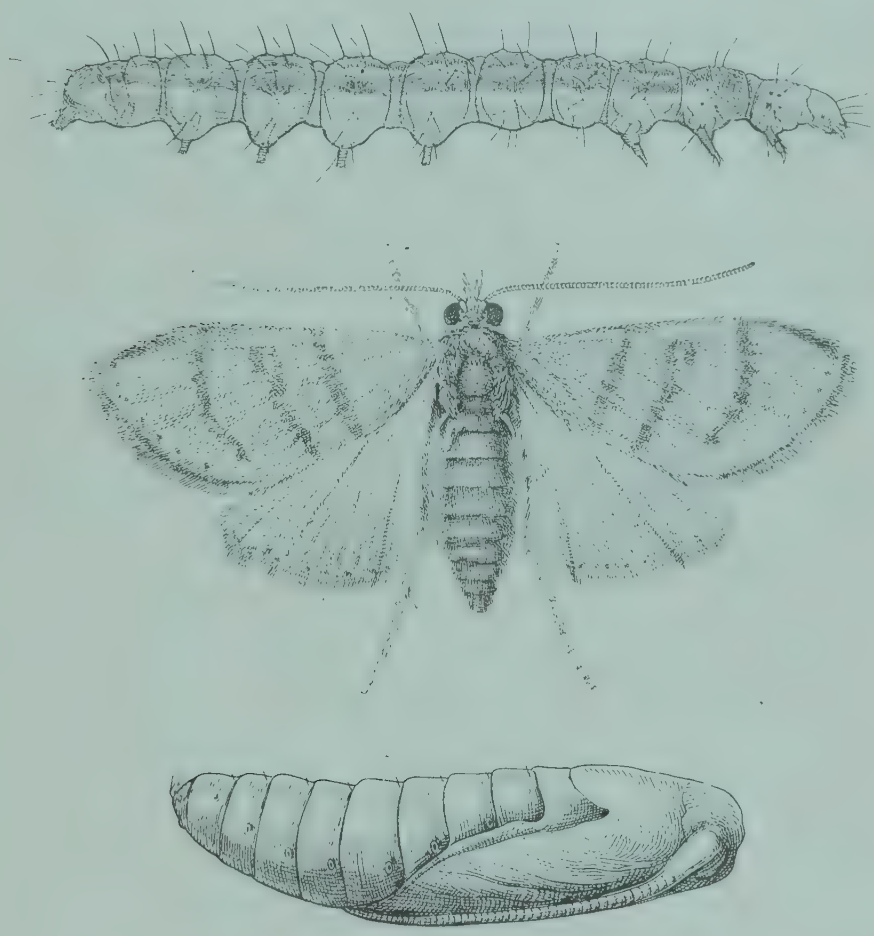

FIG. 7—Larva, pupa and moth, *Phlyctænia despecta* Butl. The larva is the sweet potato leaf-roller. 4 x nat. size.

on segments 3 and 4 this tubercle is on a line with the spiracles and anterior in the segment while (3) is on a line with it and posterior in the segment—on segment 2 there is only one tubercle, in front of the spiracle; a row (5) just below (4) and posterior in the segment—on segments with legs it is at the

outer base of same, and on segment 2 is double; a row (6) on outer side of each proleg about half-way down the leg, on the inner side of each true leg, and ventrad to (5) on legless segments—each tubercle has three setæ; a row (7) of small tubercles close to median ventral line, one to each segment; on segment 2 a number of small tubercles dorsally; spiracles brownish. The larval stage occupies 15 to 18 days.

The pupa. The pupa is formed in a slight cocoon within the folded leaf. It is brown, 7.5 mm., wing-cases extend to posterior margin of fifth abdominal segment, antennal cases a trifle beyond, and leg case to about the middle of the seventh. Stigmata on third and fourth segments conspicuously larger, projecting from the body and very knob-like. Cremaster short, truncated, and with eight hair-like hooked spines fastened into cocoon. The pupal period is 9 to 10 days.

The adult. The adult moth is described as follows*:

♂ ♀ 15-27 mm. Head, palpi, and thorax ferruginous, sometimes infuscated, palpi 3-3½, white towards base beneath, thorax sometimes suffused with ochreous-yellowish posteriorly. Abdomen grey, sometimes suffused with ochreous-yellowish or ferruginous. Legs whitish, sometimes more or less variably suffused with ferruginous. Forewings reddish-ochreous or fuscous-ochreous or ferruginous, sometimes much mixed with dark fuscous, especially towards costa on anterior half, sometimes much tinged with coppery-purplish; first line dark fuscous, bent in middle but usually obsolete on costal half; roundish orbicular and 8-shaped discal spot outlined with dark fuscous; second line waved or denticulate, dark fuscous, more or less curved on upper portion, sometimes sinuate near costa, below middle with an abrupt semicircular excavation inwards beneath discal spot; posterior half of costa sometimes spotted with dark fuscous; a terminal series of dark fuscous or blackish dots; cilia rather dark fuscous, tips obscurely whitish. Hind-wings fuscous, darker posteriorly, sometimes mixed with lighter ochreous suffusion; two obliquely placed dark fuscous discal dots; usually an indistinct darker postmedian line as in forewings; a terminal series of blackish dots; cilia grey or grey-whitish, with dark grey subbasal line.

Remedies. This moth is at times very injurious to the sweet potato but is usually well controlled by parasites. The application of arsenate of lead is recommended in case of a troublesome appearance of the caterpillars. The writer has bred *Limnerium blackburni* from the larvæ of these moths in great num-

* Meyrick, Macrolepidoptera. Fauna Hawaiiensis, vol. 1, pt. 2, p. 217. Cambridge, 1899.

bers, and it seems to be an effective parasite. Dr. Perkins has also bred *Chelonus blackburni* and *Chalcis obscurata.* A common Odynerus wasp (*O. nigripennis*) has been observed gathering the caterpillars.

THE TORTRICID LEAF ROLLER.

The tortricid leaf roller (*Amorbia emigratella*) (Fig. 8) is an introduced pest which has been known in Hawaii since about 1900. It occurs also in Mexico and Costa Rica, and was probably brought here from the former country. It has increased very rapidly, as most introduced insects do which are not checked by parasites, and its great range of food plants makes it an unusually destructive form.

The larvæ are leaf rollers on many kinds of plants, shrubs, and fruit trees, and are often so numerous as to defoliate trees, on some of which it attacks the fruit as well. The writer has found it on citrus trees, cotton, avocado, guava, rose, passion flower vine, tomato, papaya, cacao, as well as on sweet potato, and on various indigenous plants in the mountains.

The young larvæ feed much as do the small caterpillars of *P. despecta,* working beneath a coarse web. In fruits they commence to bore inside, but soon desist and work on the surface beneath a web, or fasten the fruit to the nearest object—a leaf or another fruit. They destroy the blossom in the papaya and prevent the fruit from setting.

Life history. There are four stages in the life cycle—the egg; larva or caterpillar, pupa and moth.

The egg. The eggs are laid in clusters of from 65 to 120 (sometimes only a few eggs in a cluster), usually on the upper surface of a leaf, sometimes on foreign bodies. The cluster imparts a greenish color and has a whitish protective covering which extends beyond the edge of the egg-mass. The eggs are flat, elliptical, 1 mm. long, slightly iridescent and finely reticulated (which becomes more apparent after hatching) and overlap a trifle. The greenish color changes to brownish as the ovum approaches maturity, and just previous to hatching the young larva may be seen coiled inside the egg. The egg stage occupies 10 days.

The larva. The larva on hatching is about 1.65 mm. long,

light green, head brownish-yellow, cervical shield lemon yellow. On each segment a pair of dorsal hairs which are longer on the head, cervical and anal shields. The eyes are black, mandibles dark brown, anal shield concolorous. In the course of its growth the larva molts three or four times. Full-grown larva 25 mm., head rounded, slightly bilobed, luteous, with a pair of dorsal and lateral pinkish-brown bands, a black line on lateral margin extending nearly its whole length, ocelli black, pale centered, continued caudad in a wavy black line, tips of mandibles dark brown, tips of antennæ brownish-black; body stout, cylindrical, uniform green or yellowish-green, transversely wrinkled, fat body and tracheæ showing conspicuously through thin integument; tubercles small, slightly convex, concolorous with body or slightly fuscous, each bearing a seta (sometimes two), arranged in several longitudinal rows as follows: on dorsum anterior (1) and central (2) near anterior margin and center of segments 5 to 12, the former near median line—on segments 3 and 4 these tubercles double and (1) ventrad of (2); supra-spiracular (3) one situated just above each spiracle (on segment 12 pre-spiracular); sub-spiracular (4+5) a double tubercle below each spiracle, composed of two tubercles united and bears two hairs—on segment 2 in front of spiracle—on segments 3 and 4 (1), (4+5) and (3) form a triangle in about median position in the segment, (1) double; lateral (6) one on each segment caudad of (4+5), nearer to posterior margin—on second segment double and ventrad of (4+5); marginal (7) on outer side of each proleg and inner side of each true leg—on legless segments in about the same longitudinal line ventrad of (6)—each has three setæ; ventral (8) a small tubercle near median ventral line of each segment; cervical shield concolorous with body, with black line on lateral margin; feet concolorous with body, the tips black; spiracles minute, circular, rimmed with brown and center yellowish-white—those on segments 2 and 12 larger than the others. The larval period is 28 to 35 days.

The pupa. Pupation takes place within the folded leaf. Pupa 9 to 12 mm., dark brown on dorsum shading into golden-brown on venter; wing-cases luteous, and extending beyond middle of fourth abdominal segment; spiracular openings

small, reddish-brown; on dorsum of abdominal segments 2 to 8 two transverse rows of minute blunt spines, near anterior and posterior margins, becoming smaller outwardly from median

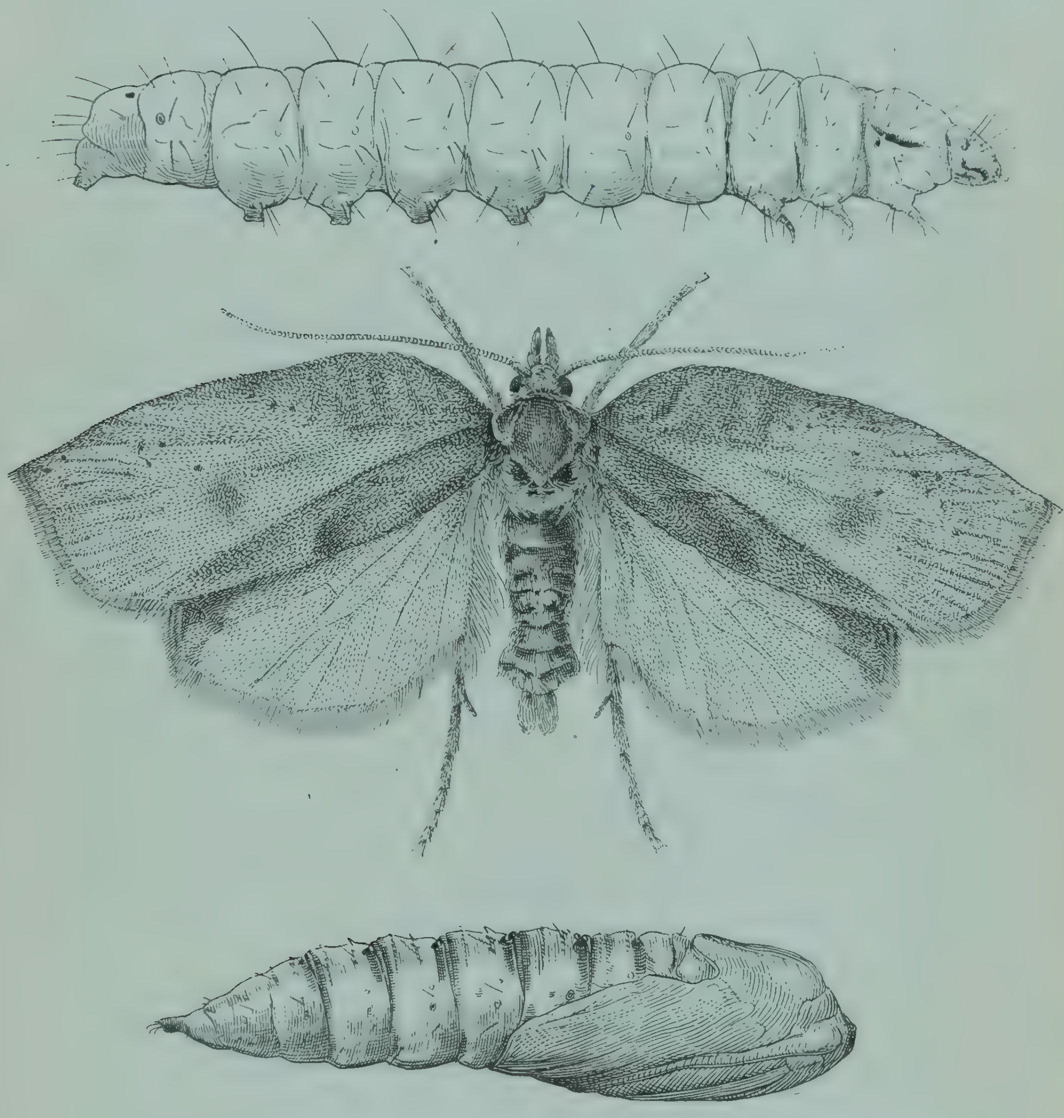

FIG. 8—Larva, pupa and moth, *Amorbia omigratella* Busck. The larva is the tortricid leaf-roller. 4 x nat. size.

line and disappearing before the spiracles; posterior row a trifle more extensive than the anterior; in front of anterior row on median line of dorsum of segments 2 to 7 a pit, partially covered by narrow blackish lip extending from posterior margin of preceding segment; on segment 9 a few scattered hairs; cre-

master moderately pointed with eight short recurved spines. The pupal stage covers 10 days.

The moth. The moth is described by Busck as follows*:

Female. Basal joint of labial palpi short, ochreous; second joint long prorected, rust-red with a violaceous sheen on the tip; terminal joint short, reddish brown, shaded with black. Face behind the palpi short-scaled, whitish; head reddish brown, mixed with ochreous and with a short pointed frontal tuft. Antennae reddish brown, simple. Thorax and patagia uniformly dark brown. Forewings with base of costa strongly arched; costal and dorsal edges nearly parallel; apex squarely pointed; termen slightly sinuate below apex, thence evenly rounded; ochreous brown, shading into light ochreous on the terminal third; the edge between two colors is not sharply drawn, but the limits are still quite distinct, the lighter color occupying the area below a straight line from basal fourth of the dorsal edge to apex. From just before the middle of costa runs an indistinct, dark bluish-gray band obliquely outward towards tornus, but fades out in the ochreous part of the wing and is even interrupted in the brown costal part; parallel with this is another similarly colored, but less distinct streak at apical third, also disappearing in the light portion of the wing. On the dorsal edge at basal fourth and at the middle are two short dark gray streaks, parallel with the costal streaks. The entire wing is finely mottled with a close transverse apparently darker striation, which is produced by transverse rows of slightly elevated scales. These markings are of varying intensity in different specimens, some showing hardly any trace of the darker cross-bands and having the ground-color lighter and nearly unmottled except for the fine transverse striation caused by the slightly raised rows of scales. Hindwings light straw-yellow, with the apex mottled with dark brown and black and with the costal cilia absent and abruptly beginning again just before the tip of the wing. Cilia straw-white. Underside of the forewings reddish ochreous, with a blackish terminal line before the cilia. Abdomen light yellow. Legs straw-yellow; the anterior and middle legs shaded with reddish brown exteriorly and with the tarsi faintly annulated.

Alar expanse 27 to 29 mm.

Male. Of considerably smaller size and of a general lighter color. Forewings nearly uniformly light ochreous without the darker basal and costal shade. The first costal dark streak is represented by a dark bluish brown triangular spot, terminating in a nearly black dot; the second costal streak is replaced by a faint, curved, dark line, emitted from a small bluish brown costal spot. The transverse striation caused by the rows of slightly raised scales is apparent. The antennae are pectinated.

While the two males from Hawaii before me do not exhibit much variation, a similar range of variation as is found in the females may be expected in the males.

Habitat. Tantalus and Makiki, Oahu, Hawaiian Islands. O. H. Swezey, Collector.

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*Proc. Ent. Soc. Wash., 9 (1909), p. 201.

Remedies. On account of the many leaf-feeding caterpillars, sweet potatoes must be sprayed four or five times during the year with an arsenical poison. The attacks of hornworm and Phlyctænia, which seem to be more destructive of the foliage than the others, will determine when this spraying is to be done, and the remedy for these pests will also be effective against the others. Arsenate of lead is recommended as the most useful form of arsenic and the one the least likely to burn the foliage. The tortricid leaf roller is parasitized by *Chalcis obscurata,* which does something to mitigate its destructiveness. Unfortunately the very valuable egg parasites (*Trichogramma* spp.), which contribute more than any others to keep this class of pest in check, are unable to penetrate the tough covering of the *Amorbia* eggs.

THE SWEET POTATO WEEVILS.

There are two weevils attacking the tuber or rootstock of the sweet potato in Hawaii. They are quite distinct insects; one small, square-bodied, dark grayish brown, and the other long, slender and metallic. They are both introduced pests and are quite destructive at times.

The smaller one is the insect recorded in the Fauna as *Hyperamorpha squamosa* Blackburn and at another time determined as a native Acalles. It is now believed to be the common West Indian form, *Cryptorhynchus batatae* Waterhouse (Fig. 9). It is the commoner of the two in Hawaii, and the author has found it infesting sweet potatoes from Maui and Oahu, but did not find it generally prevalent. The following description is copied from Ballou*:

Cr. oblongo-ovatus, nigro-piceus; squamosus, supra spinulus erectus nigris et pallidis obsitus; *rostro* brevi, crasso, arcuato, ruguloso-punctato, carinato; *thorace* ruguso-punctato, setis (plerumque nigris) obsito, postice squamulis flavidis marginato, dorso linea, punctisque parvulis, albis, notato; *elytris* ocellato-punctato striatis, interstitiis fere planis, fusco, nigro, alboque variegatis, plaga communi, transversa, sordide alba, subapicali, ornitis; *femoribus* indistincte dentatis; *scutello* minutissimo.

Long. corp. 2 lin. Hab. Barbados.

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* H. A. Ballou, The Scarabee of the Sweet Potato. West Indian Bul. 10 (1909), No. 2, p. 180.

This is a minute species of *Cryptorhynchus*, and differs somewhat from the type of the genus—if we regard the *C. lapathi* as such—though not sufficiently, as it appears to me, to require removal from that section. Its form is more elongated, and its scutellum is so minute as to require the aid of a strong lens to detect it; the insect nevertheless has well-developed wings; the rostrum is stouter, and subdepressed, and is inserted in a very deep rostral groove, which terminates

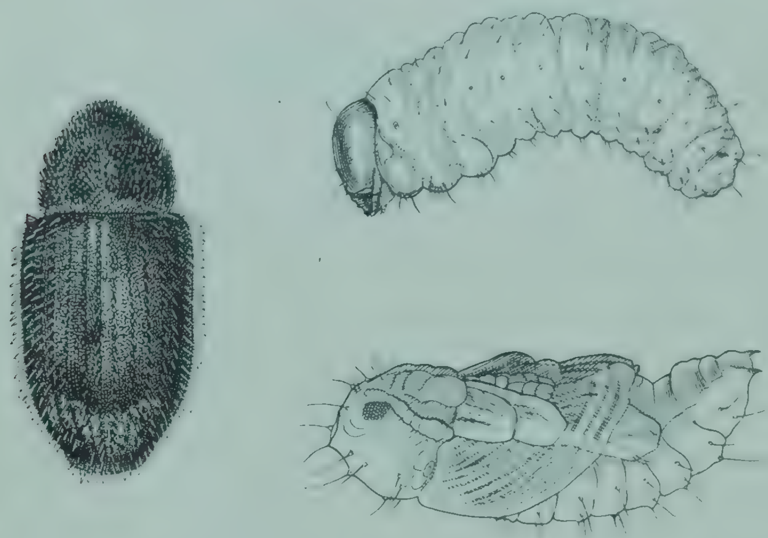

FIG. 9—Larva, pupa and adult, *Cryptorhynchus batatæ* Waterh., a common sweet potato weevil. 12 x nat. size.

between the coxae of the anterior pair of legs; the scape of the antennae is shorter and stouter, the basal joint of the funiculus is also stouter, the second joint is of an elongate obconic form, the remaining joints are also obconic, but very short; the club is tolerably developed, and of a short ovate form: the femora are rather less stout, and very indistinctly toothed beneath.

The head is covered chiefly with pale scales, but has two black spots; the thorax is rather broader than long, rather suddenly contracted in width from the middle to the fore part, and with the lateral margins of the hinder half nearly parallel, being very slightly rounded; the upper surface is densely beset with short, stiff, erect bristles, which are most of them black, but some few are white, and are aggregated in parts so as to form small spots and a white mesial line; the hinder margin is clothed with orange-yellow scales, and these form a small spot near the scutellum. The elytra are more than three times the length of the thorax, and about half as wide again, the humeral angle is rounded, the sides nearly parallel, except towards the apex, where they are rather suddenly contracted, and obtusely rounded: they are covered with scales, some of which are dirty white, others brown, and others black, producing a variegated appearance; in each of the tolerably large punctures of the striae is a white scale: on the fourth interstice from the suture is a small white spot, which is rather more con-

spicuous than others; it is situated above the middle of the elytron, and at a short distance from the apex of the elytra is a conspicuous transverse dirty white patch, in which is a waved black line. Besides the scales there are scattered dark and pale hairs on the elytra. On the under parts of the insect are scattered pale scales. The limbs are clothed with setiform scales, most of which are pale.

The eggs of the weevil are laid on the surface of the sweet potato and the larvæ or grubs bore into the interior. The larval stage is somewhat prolonged and is passed entirely within the potato, which becomes badly riddled and decayed. The larvæ pupate inside and later the adults emerge. This insect has not so far been bred at the station so as to get the length of time required for the different stages.

Remedies. This insect is very common in the Barbados and Antigua of the Lesser Antilles and is often very destructive. Experiments have been made there with vaporite, carbon bisulphid, corrosive sublimate, and arsenic, as a mean of controlling the pest, but they were found to be totally ineffective. They recommend, as the only measure of practical value, the destruction of all infested potatoes and the trash above ground by burning it in lime. In the case of a repeated recurrence of the weevil in sweet potato fields, it would be advisable to plant in another locality.

The larger of the weevils is the widely distributed *Cylas formicarius* (Fig. 10), a native probably of Cochin China, but now found in India, China, Madagascar, Southern United States, West Indies, Northern Australia—and generally over the Tropics. It is not very common in Hawaii. It breeds in stems of *Ipomoea pes-caprae,* which grows everywhere along sandy beaches, as well as in the sweet potato. The occurrence of this weevil at Lahainaluna, Maui, in January, 1907, brought it into prominence as a pest in Hawaii and the insect was discussed by Van Dine in the Annual Report of this station for that year. The following is a description of its appearance and life history*:

The beetle is somewhat ant-like in form. The color of the elytra [wing covers] and of the head and beak is bluish black; that of the prothorax is reddish brown. The yellowish-white oval eggs are laid in small cavities eaten by the parent bettles near the stem end of the tuberous roots. The milk-white larvae bore little tunnels through the

* Hawaii Sta. Rpt. 1907, p. 29.

root in all directions, so that the vine dies: and frequently the entire potato is tunneled; these burrows become filled behind the larvae with excrement. When about to assume the pupa state, the insect forms an oval cavity at the end of its burrow, where it undergoes its transformation.

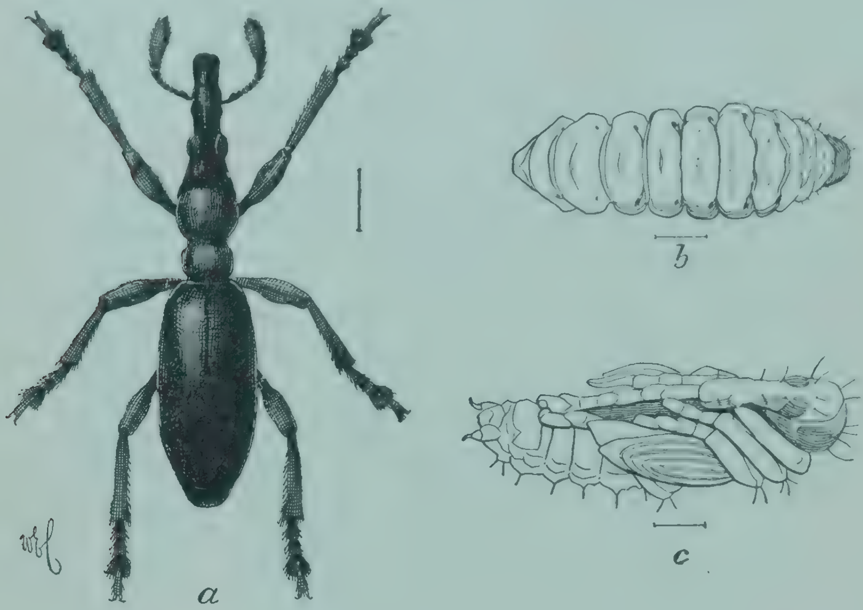

FIG. 10—Larva, pupa and adult, *Cylas formicarius* 01., a common sweet potato weevil. 7 x nat. size.

Remedies. No remedy of general application can be suggested for this pest. Infested material should be burned or destroyed with lime. In case of a serious infestation, a new location should be secured if practicable, or sweet potato growing abandoned for a time and some other crop substituted. This will materially reduce the prevalence of the weevils and in time sweet potatoes may be grown again without being infested.

MINOR PESTS.

There are a few minor pests of the sweet potato. *Nesosydne ipomoeicola* and *Aloha ipomoeae* are two common leaf hoppers on this plant. *Plusia chalcites* sometimes attacks the foliage. A mealy bug (undetermined species of Pseudococcus) and a scale insect (*Saissetia* sp.) are commonly met with, and the Japanese beetle (*Adoretus tenuimaculatus*) occasionlly attacks it and skeletonizes the leaves.

The leaf hoppers are much parasitized by Anagrus, Stylops

and Echthrodelphax and are of no importance as pests. Plusia is not very destructive and is heavily parasitized by tachinid flies. The coccids are of no great importance, and the Japanese beetle only occasionally becomes troublesome.

BENEFICIAL INSECTS.

Specific parasites have been mentioned in connection with each pest. It remains to enumerate a few general parasitic or predaceous forms. Wasps of the genus Odynerus prey on caterpillars of medium-sized Lepidoptera, which they store in nests as food for their young. Probably the commonest species at low elevation is *O. nigripennis.* The Polistes wasps also prey on these caterpillars, which they devour to obtain food for their young. The writer has found the following predaceous bugs active on the sweet potato: *Oechalia grisea, Zelus renardii* and *Reduviolus blackburni.* Oechalia attacks caterpillars and sucks out their body juice; Zelus and Reduviolus attack smaller forms —leaf hoppers, leaf miners, etc.

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HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 24.

THE ASSIMILATION OF NITROGEN BY RICE.

BY

W. P. KELLEY,

CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:

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[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

Walter H. Evans, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *February 27, 1911.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 24 of the Hawaii Agricultural Experiment Station, a paper on the Assimilation of Nitrogen by Rice, prepared by Mr. W. P. Kelley, chemist of the station. The formulas for fertilizers heretofore used for rice in Hawaii have been based on experiments in which insufficient attention was given to the comparative effects of the different forms of nitrogen. The experiments reported in this bulletin indicate quite conclusively that nitrates are unsuited as fertilizers for rice, while excellent results are secured by the use of nitrogen in the form of ammonia. The bulletin should, therefore, lead to changes in cultural practice which will bring about greater profits. From a scientific standpoint, also, the careful pot experiments in which nitrates are shown to be ineffective and harmful, and ammonia very effective, should be of considerable interest.

Respectfully.

E. V. WILCOX,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

THE ASSIMILATION OF NITROGEN BY RICE.

INTRODUCTION.

The absorption of plant food and the chemical changes that take place in the formation of organized living tissue from the inorganic substances of the soil and air are subjects that have long occupied the attention of scientists. During the past century certain phases of this question were investigated in no small measure, and among these perhaps none received more study and played a greater part in the development of agricultural science than that which pertains to the utilization of nitrogen in plant growth. The history of this question marks a progressive evolution, and connected with it are to be found the names of prominent chemists and biologists in many countries.

As a result of these researches, it has come to be generally accepted that practically all cultivated plants, with the possible exception of the legumes, absorb nitrogen in a combined form and preferably as nitrates. Without tracing the chronological development of these investigations, it is sufficient to say that to-day it passes current and is generally taught in agricultural texts that whatever be the form of combined nitrogen applied to the soil, bacterial changes result in its transformation into nitrates before it can be absorbed by plants. Nitrogenous fertilizers are said to be valuable in proportion to the rate at which they become nitrified. Thus it is common to refer to the nitrogen of hoof-and-horn meal as having less agricultural value than that of dried blood or ammonium sulphate, and even these latter substances are sometimes spoken of as slow acting, by which it is meant that nitrification must take place before the higher plants can utilize their nitrogen. The prevailing idea is traceable to the fact that nitrates are considered to be immediately available, whereas other forms including ammonium salts are not. This view receives support from the fact that all forms of nitrogen in the soil tend to become converted into nitrates under conditions favorable to plant growth, and in addition that the direct application of nitrate gives indications of its immediate absorption, while other forms do not usually act so readily.

While it is true that the application of nitrates usually results in greater economy and stimulates plant growth to a greater degree than ammonium salts, it does not necessarily follow from this that the former can be the more easily transformed into proteids, nor that

nitrates occurring naturally in soils are really more easily assimilated than the naturally occurring ammonium compounds, for on the one hand it is not impossible that the basic ion combined with the nitrate exerts a stimulating effect, while on the other, the acid radicle of the ammonium salt may be injurious. This view appears the more tenable when it is considered that most cultivated soils have a decided tendency to become acid. Furthermore, nitrates are very soluble, and not being fixed to any great extent, become diffused throughout the soil, whereas ammonium salts are fixed and held more firmly and therefore, do not circulate as freely in the soil moisture. Consequently, it is reasonable to suppose that nitrates come in contact more freely with the active root hairs of plants.

In the process of nitrification ammonia represents one stage in the oxidation of organic nitrogen, and if conditions are not favorable for complete oxidation, the process may end at this point. In arable soils it is not infrequent to find rather large quantities of ammonia. Fraps,[1] for instance, found that the ammonia content of some Texas soils exceeded the nitrates, and that the application of certain organic nitrogenous fertilizers resulted in the accumulation in the soil of greater quantities of ammonia than of nitrates. This author refers to active nitrogen as including both nitrates and ammonia, and points out that in considering the available nitrogen of soils, greater attention should be given to ammonia.

Russell and Hutchinson[2] have recently shown that the increased fertility of soils following partial sterilization is due to accelerated ammonification, rather than the formation of nitrates, which again points to the importance of ammonia in plant nutrition.

Notwithstanding the prevalance of the idea that nitrates are necessary for plant growth, experiments are not wanting to show that other forms can function in normal plant nutrition. During the period of 10 years following 1884 Pitsch[3] conducted experiments with various plants under conditions that exclude nitrification, and found that ammonium salts were directly assimilated, but he also found that the yields were greater from the use of nitrates, especially during the early growth of the plants. Müntz[4] in 1889, and Griffiths[5] about the same time succeeded in growing beans, maize, barley, and hemp with ammonium salts as the only source of nitrogen. Similar experiments have been performed by a number of other investigators, but concordant results have not always been obtained. Recently Hutchinson and Miller[6] conducted a series of experiments with wheat

[1] Texas Sta. Bul. 106.

[2] Jour. Agr. Sci., 3 (1909), No. 2, pp. 111-114.

[3] Landw. Vers. Stat., 34 (1887), pp. 217-258; 42 (1893), pp. 1-95.

[4] Compt. Rend. Acad. Sci. [Paris], 109 (1889), pp. 646-648.

[5] Chem. News, 64 (1891), p. 147.

[6] Jour. Agr. Sci., 3 (1909), No. 2, pp. 179-194. These authors also give a very complete summary of the work done in this connection.

and peas in water and sand cultures under sterile conditions, and in practically every instance as satisfactory results were obtained from the use of ammonium sulphate as from nitrate of soda.

From the results of these and other experiments it may be concluded that some plants can utilize ammonium nitrogen equally as well as nitrate nitrogen, while others prefer nitrates, but it is uncertain that ammonium salts can ever produce better results than nitrates.

CONDITIONS IN RICE SOILS.

The process of nitrification is essentially one of oxidation. The bacteria affecting the chemical changes in this process require a free circulation of air in order to best accomplish these oxidations. In the absence of free circulating air nitrification proceeds at best at a very slow rate and probably ceases altogether. In water-logged or saturated soils natural aeration is reduced to a minimum. Rice is cultivated in just such soils. The land used in rice culture is usually puddled before planting in order to reduce the loss of irrigation water through natural drainage and seepage, and during the main growing period of the crop the soil is kept completely submerged. In other words, rice is grown in standing water and consequently in a saturated soil. It is reasonable, therefore, to suppose that under such conditions nitrification proceeds at a slow rate, if at all. In fact it is more likely that denitrification takes place, for in addition to being submerged, rice soils frequently contain large quantities of organic matter which is conducive to a reduction and probably to denitrification. Hence it is not without interest to inquire into the question of the absorption of nitrogen by rice.

NITROGEN EXPERIMENTS WITH RICE, HISTORICAL.

Kellner [1] in 1882 found that swamp rice in pots during its early development made better growth with ammonium salts than with nitrates, but during later growth nitrates proved the more effective. A combination of the two forms of nitrogen seemed best adapted to this culture. The total yield from the use of nitrates alone considerably exceeded that obtained from the use of ammonium nitrogen, whereas a combination of the two forms of nitrogen produced the greatest yield. Later the same author showed that the formation of nitrates in paddy soils of Japan [2] takes place very slowly, while ammonia is formed in rather large quantities.

In a bulletin on rice culture in Louisiana, Dr. Stubbs [3] in 1900 made the following statement: "All cultivated crops utilize nitrogen in the form of nitrates," and further on he says, "recent investigations at this station show that rice gets its nitrogen as nitrates."

[1] Landw. Vers. Stat., 30 (1884), pp. 18–41.
[2] Col. Agr., Tokyo Imp. Univ., 1 (1891), No. 9, pp. 1–25.
[3] Louisiana Sta. Bul. 61, pp. 396, 397.

In 1904[1] the same author, in association with Dodson and Brown in discussing some sand cultures in which different forms of nitrogen were used, says: "The pot containing ammonia made quite vigorous growth, indicating the utilization of nitrogen in this form."

In 1905 Nagaoka[2] conducted a large number of pot experiments with wet-land rice by means of which he was able to compare the effects produced by the use of different nitrates, ammonium sulphate, etc. In some of these experiments he found that nitrates produced practically no effect, while in others a considerable increase was noticeable. Ammonium sulphate, however, produced noteworthy effects in every instance. This author also conducted similar experiments with dry-land and swamp rice, each being grown with and without irrigation, and again ammonium sulphate was superior to nitrates, although the effects of nitrate was relatively greater in the dry-land culture than under irrigation. For use in swamp-rice culture Nagaoka concluded that the value of ammonium sulphate and nitrates stand in the ratio of 100 to 40.

In 1906 Fraps[3] published a bulletin dealing with rice soils in Texas, in which it is shown that nitrification takes places very slowly in submerged rice soils, whereas ammonium formation proceeds more rapidly. He also states that rice probably absorbs a considerable portion of its nitrogen from ammonium compounds, since during the main growing period the soil contains much larger quantities of ammoniacal nitrogen than of nitrates.

In 1907 Daikuhara and Imaseki[4] found from pot experiments that for irrigated rice ammonium sulphate was much more effective than either nitrate of soda or a combination of the two forms. The value of the nitrate was also found to be greatly reduced in the presence of organic matter. When the rice was grown as a dry-land crop, however, nitrate of soda and ammonium sulphate proved to be of about equal value.

Experiments already reported from this station[5] also indicate that ammonium sulphate is a more effective carrier of nitrogen in rice culture than nitrate of soda, although concordant results have not always been obtained. From the foregoing it is apparent, therefore, that the question of the form in which nitrogen is absorbed by rice is far from being settled. It is important that we have more definite knowledge concerning this question, for such knowledge will not only enable the farmer to better select his fertilizer, but also may suggest the advisability of a modification of the system now employed in rice culture, especially in Hawaii and on the mainland. Among the Chinese rice growers in Hawaii it is quite common to use cane fer-

[1] Louisiana Sta. Bul. 77, pp. 392, 393.
[2] Bul. Col. Agr., Tokyo Imp. Univ., 6 (1904), pp. 285–334.
[3] Texas Sta. Bul. 82.
[4] Bul. Imp. Cent. Agr. Expt. Sta. Japan, 1 (1907), No. 2, pp. 7–36.
[5] Hawaii Sta. Rpts. 1907 and 1908.

tilizers, such as is applied on the cane lands near by, and which often contain nitrogen in two or more forms. Furthermore, the scientific phase of this question is of no little importance. Consequently an investigation of the question is not without interest.

FIELD TRIALS.

Accordingly this station for the past two years has conducted fertilizer experiments with rice. Field experiments under practical conditions have been made at the rice trial grounds on a uniform piece of land, which proved to be well adapted to experiments of this nature. The soil is deficient in nitrogen without at the same time requiring other fertilizers. In fact, the application of various nonnitrogenous substances has in practically every instance failed to show any influence on the crop; while marked influences have consistently followed the application of certain nitrogen fertilizers. The plats used in these experiments were separated by low dikes constructed of puddled soil and rendered practically impervious to the passage of water, in order to prevent interchange of fertilizing substances. The soil was prepared just as is done in field practice. In Hawaii rice seedlings from 20 to 30 days old are transplanted by hand from seed beds to the field. The soil after being thoroughly prepared is flooded and completely submerged before transplanting the seedlings, and the irrigation is usually continued throughout the main growing period. Two crops of rice are grown on the same land each year.

To one plat ammonium sulphate was applied, to another nitrate of soda, a third plat received ammonium sulphate at intervals of ten days in six equal applications, and finally one plat was treated with nitrate of soda which was also applied in six equal applications at intervals of ten days. Each of these plats received the same amount of nitrogen, viz, 70 pounds per acre. Applications in other experiments near by indicated this to be about the maximum amount that could be profitably used on this soil.

The following table will give the yield in pounds per acre of straw and paddy obtained from three successive harvests:

Yields from field experiments.

Nitrogen applied.	Fall crop, 1909.			Spring crop, 1910.			Fall crop, 1910.		
	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Ammonium sulphate (applied before planting)	3,168	4,603	7,771	3,316	3,564	6,880	2,920	4,010	6,930
Nitrate of soda (applied before planting)	1,881	2,475	4,356	2,029	2,128	4,157	2,227	3,312	5,539
Ammonium sulphate (applied in six applications)	2,475	3,465	5,940	2,772	3,078	5,850	2,722	3,762	6,484
Nitrate of soda (applied in six applications)	2,277	2,623	4,900	1,633	2,079	3,712	1,831	2,427	4,258
Check	....	....	....	1,930	2,178	4,108	2,145	2,762	4,907

From these data it is apparent that the application of nitrate of soda produced only slight effects on the yields either when applied in one application before transplanting or when applied at intervals during the growth of the crop. Ammonium sulphate, on the other hand, brought about considerable increase in yield, although the single application proved the more beneficial.

Rice soils in common with many other soils throughout the islands are extremely porous and naturally drain away large quantities of water. As previously mentioned, it is common among the rice growers to puddle the soil in order to reduce drainage and seepage, but in spite of every precaution considerable water passes through the soil. If the inflow be shut off the submerging water will pass below the surface in a few hours, thus indicating that rather large volumes of water drain away in this manner. Ammonium sulphate, however, is fixed by the soil to a much greater extent than nitrate of soda and the latter would consequently suffer greater loss by leaching than the former. It may be that in case of the application before planting the nitrate was largely leached below the zone of root penetration before the seedlings began active growth. Even in the case of the repeated applications it is possible that serious loss was brought about in this way. It is improbable, however, that the inefficiency of the nitrate applications was brought about entirely in this manner, for the yields from the single application were greater two times out of three than the yields from the repeated applications. It is also of interest to note that the yields from the single application of ammonium sulphate were in every instance greater than from the repeated applications.

POT EXPERIMENTS.

In addition to losses through leaching, other factors demand consideration. It is important to know not only whether nitrates are leached out of reach of the roots, but also whether denitrification may not play a prominent part. As previously pointed out, the conditions in rice soils are such as naturally suggest denitrification and consequently loss of nitrogen. The reduction of nitrogen compounds in soils is brought about by bacteria, of which there are a number of species. One class of these converts nitrates into nitrites, another reduces nitrites to free nitrogen, while still another class has the power of converting inorganic forms into insoluble albuminoids. The conditions under which each of these classes of bacteria is most active are the absence of free oxygen and the presence of an abundant source of energy, such as carbohydrates. In submerged rice soils each of these conditions is fulfilled in a large measure.

With a view of throwing more definite light on these questions, a considerable quantity of soil from the rice field was taken to the laboratory for use in pot experiments. In the field the irrigation

water is cut off and the soil allowed to dry for a week or 10 days before harvest. Immediately after harvest the land is plowed and left fallow until the time of preparation for another crop. In this way the soil dries out and becomes quite thoroughly aerated. The soil used in the pot experiments was taken from the field after having been aerated for two months. By analysis it was found to contain 0.189 per cent total nitrogen, with 55 parts per million of nitrates, 10.8 parts per million of ammonia, and a trace of nitrites.

The pots employed in this work were of a Japanese design and made of glazed porcelain provided with an aperture at the bottom by means of which drainage can be effected if desired. In these experiments the apertures were closed so as to prevent leaching. Each pot was filled by placing a layer of gravel in the bottom, on top of which were placed about 2 inches of coarse volcanic sand and then 4 kilograms of well-prepared soil. Each pot received the same quantity of a basic fertilizer composed of sulphate of potash and superphosphate. The soil was neutral and in addition was not deficient in lime.

The nitrogenous fertilizers used include ammonium sulphate, sodium nitrate, calcium nitrate, magnesium nitrate, and soy-bean cake, applied in series of three pots each, and in quantities so as to provide 0.6 gram of nitrogen per pot. The entire amounts of these substances, except in Series VI and VII, were thoroughly mixed with the dry soil, after which each pot was irrigated with nitrogen-free water in sufficient quantities to provide a column of about 2 inches above the surface of the soil. Five uniform seedlings of a Japanese variety were transplanted to each pot on the following day, April 15. On each succeeding day water was again added to replace that lost by evaporation and transpiration. The pots in Series III received a second application on May 28, thus providing this series with double the amount of nitrogen supplied to any other. The nitrogen in Series VI and VII was divided into four equal parts and applied at intervals of 10 days, the first application being made before planting.

At intervals during the growth of the rice, nitrates, nitrites, and ammonia were determined in samples of the soil and water from each pot. These tests showed that nitrites were formed in all the pots within from 5 to 10 days after having been irrigated, and were developed in considerably greatest amounts in the pots to which nitrate had been added. At the end of 20 days only a faint reaction for nitrite was obtained in any case, except where additional application of nitrate had been made. In no instance did nitrites accumulate to an extent greater than two parts per million of the irrigating water. A slight increase in nitrites followed the application of ammonium sulphate and a still greater amount was developed where soy-bean cake was used, but uniformly the greatest accumulation of nitrites

was found in the pots to which nitrates had been applied. In Series VI and VII nitrites usually disappeared within from 5 to 10 days following the nitrogen applications. The amounts of nitrate and ammonia present in the pots are shown in the following table:

Parts per million of nitric acid and ammonia in pots.

Series.	Nitrogen applied.	Apr. 28.		May 6.		May 16.	
		NO_3.	NH_3.	NO_3.	NH_3.	NO_3.	NH_3.
I	Calcium nitrate	11.3	18.0	3.6	18.5	(1)	(1)
II	Magnesium nitrate	9.0	19.2	7.2	18.0	7.0	18.0
III	Sodium nitrate	9.0	16.8	5.9	20.4	7.2	18.0
IV	Ammonium sulphate	9.0	76.8	7.2	85.0	7.2	58.9
V	Soy-bean cake	18.0	64.8	5.9	59.3	14.4	63.4
VI	Sodium nitrate (in four applications)	72.0	(1)	18.0	20.4	36.0	18.2
VII	Ammonium sulphate (in four applications)	18.2	(1)	9.0	36.2	9.0	45.3
VIII	Check	18.2	14.4	5.9	18.2	9.0	13.6

[1] Not determined.

A study of this table reveals some interesting facts. It should be kept in mind that the soil before having been irrigated contained 55 parts of nitrate per million and 10.8 parts of ammonia. Thirteen days thereafter nitrates were present to the extent of less than one-third of the former amount, while the ammonia content had become practically doubled. At the end of 10 days later the nitrate content had become reduced to a low minimum, whereas the ammonia was being maintained. It is surprising to note that the nitrates disappeared so soon after having been applied. In no instance was there a maintenance of the nitrate content, except in the case of the repeated applications. Many tests not recorded in the table, showed that nitrates disappeared in this soil within five days from the time of application. It is of interest in this connection that the application of ammonium sulphate or soy-bean cake resulted in considerably increasing the ammonia in the soil, and that a slight increase in ammonia followed the application of nitrates.

In order better to compare the growth of the rice in these pots, measurements of the height of the plants at different periods of growth were made. These measurements are recorded in the following table:

Average height in inches of rice in pots at different intervals.

Series.	Nitrogen applied.	May 11.	May 28.	May 31.	June 6.	July 16.
I	Calcium nitrate	18.5	31	32.5	33.5	41
II	Magnesium nitrate	19.0	30	30.5	32.5	41
III	Sodium nitrate [1]	19.0	30	31.5	33.5	44
IV	Ammonium sulphate	24.0	36	39.0	42.0	48
V	Soy-bean cake	21.0	33	35.0	36.0	46
VI	Sodium nitrate (in four applications)	19.0	31	32.0	36.0	46
VII	Ammonium sulphate (in four applications)	21.0	34	37.0	39.0	38
VIII	Check	20.0	30	31.0	32.0	40

[1] This series received an additional application May 28.

The effects of the ammonium sulphate were noticeable within one week from the time of transplanting and became more and more apparent throughout the main growing period. Soy-bean cake produced results intermediate between the unfertilized and the ammonium sulphate series. The increase in height, however, does not fairly represent the full effects of the treatment, for the rice that was fertilized with ammonium sulphate stooled, or tillered, to a much greater extent than when it was fertilized with nitrates or unfertilized. The average number of the fruiting stems produced from the use of ammonium sulphate was six for each seedling transplanted, while the unfertilized and nitrate series each had an average of three. Nitrates appeared to exert no influence on the rice, neither in the size and number of the fruiting stems nor in its color or appearance, until the crop had passed through a considerable period of its growth. Near the time of heading nitrate seemed to exert a stimulating effect and was most pronounced in Series III and VI, to which additional applications were made.

The rice was cut on July 17 and after having become thoroughly air dried was weighed and subjected to analysis for nitrogen. The results are recorded in the following table:

Average yields and nitrogen absorbed per pot.

Series.	Nitrogen applied.	Straw.	Paddy.	Total.	Nitrogen in—		
					Straw.	Paddy.	Total.
		Grams.	*Grams.*	*Grams.*	*Per ct.*	*Per ct.*	*Grams.*
I	Calcium nitrate	35	26	61	0.361	0.862	0.3504
II	Magnesium nitrate	28	22	50	.398	(1)	....
III	Sodium nitrate	37	39	76	.428	.947	.5276
IV	Ammonium sulphate	72	46	118	.388	.960	.7309
V	Soy-bean cake	56	41	97	.420	.960	.6288
VI	Sodium nitrate (in four applications)	38	33	71	.388	(1)	....
VII	Ammonium sulphate (in four applications)	61	44	105	.404	(1)	....
VIII	Check	27	20	47	.408	(1)	....

[1] Samples destroyed by mice before being analyzed.

The above table shows that markedly increased growth was produced from the use of ammonium sulphate or soy-bean cake, while only a slight increase followed the use of calcium and magnesium nitrates. Series III, it should be remembered, received an additional application of sodium nitrate on May 28, which seemed to bring about some increase in growth; likewise the repeated applications in Series VI also produced noticeable effects. The percentage of nitrogen in the straw and grain was in no instance greatly affected by the fertilizer, and from the amount of nitrogen absorbed by the total plant it is apparent that greater assimilation of nitrogen followed the use of ammonium sulphate or soy-bean cake than the use of nitrates.

By again referring to the table (p. 12), it will be seen that the application of nitrates did not permanently increase the amount of nitrate in the soil. Usually no increase was detected later than five days after the time of making the application, but on the other hand, an increase in the ammonia content of the soil followed the application of nitrate. From these facts it seems reasonable to suppose that at least a part of the influence brought by the application of nitrates may be traceable to the fact that they gave rise to an increase in ammonia. This seems the more reasonable when we consider that nitrates were not developed from the use of ammonium sulphate, but a permanent increase in the recoverable ammonia was brought about in this way, and at the same time increased growth was produced. In addition, we find by comparing the height of the rice in Series IV and VII on the one hand and the ammonia present on the other that growth was proportional to the amount of ammonia present.[1]

EXPERIMENTS IN ERLENMEYER FLASKS.

With the view of determining whether the reduction in the amount of nitrates present in the original soil and the disappearance of nitrates added to the pots were due to denitrification or to the nitrates having been absorbed by the rice, additional experiments were made in Erlenmeyer flasks. On April 19, 100 grams of soil with 100 cubic centimeters of distilled water were added to each flask. Ammonium sulphate, nitrate of soda, and soy-bean cake were then added in a series of three flasks each. After thoroughly mixing the flasks were placed in a dark room and tested from time to time for nitrites, nitrates, and ammonia. In each flask nitrites were developed to a slight extent and were found present to the greatest extent in the flasks to which nitrate of soda was added. In no instance did the nitrite exceed more than two parts per million of the original soil. The following table shows the nitrates and ammonia in these flasks at three different times during the first month:

Parts per million of nitric acid and ammonia in flasks.

Nitrogen applied.	Apr. 28.	May 5.		May 19.	
	NO_3	NO_3	NH_3	NO_3	NH_3
Sodium nitrate	675.0	540.0	23.8	270.0	17.0
Ammonium sulphate	11.0	10.8	102.0	8.1	91.8
Soy-bean cake	6.7	17.9	81.6	5.6	56.0
Check	11.0	8.1	27.2	5.4	27.2

[1] Previous experiments have shown that rice absorbs a large part of its nitrogen during early growth. Consequently greater yields may be expected where an abundant source of available nitrogen is present. See Hawaii Sta. Bul. 21.

These data show that the disappearance of nitrate is due to denitrification and indicates that such change probably accounts for the loss of nitrates in the previous pot experiments. The flasks to which nitrate was added rapidly lost nitrate, so that within one month over one-half of that added had either become converted into insoluble albuminoids or lost as free nitrogen.

From the foregoing experiments it is evident that nitrate is not a suitable form of nitrogen for paddy soils. The nitrates that accumulate during the period between crops of rice while the soil is dry and aerated do not to any considerable extent function in the nutrition of rice because they are soon converted into lower forms and probably lost as gaseous nitrogen, while the amount of ammonia in the soil considerably increases after being irrigated and can be permanently increased by the application of ammonium sulphate or organic nitrogen. With such increase, increased growth of rice follows. On the other hand, only a small increase in growth was produced by supplying the crop with nitrates, not even under conditions that prevented the loss of nitrogen through drainage. In practice organic or ammonia forms of nitrogen should be employed.

EXPERIMENTS WITH SAND CULTURES.

From the scientific standpoint it is of interest to carry these experiments a step further. In the previous experiments both nitrates and ammonia were available to the growing plant. While it is true that nitrates exist in Hawaiian rice soils to no such extent as ammonia, it is not certain from the foregoing experiments that the small amount of nitrates present did not function advantageously to the rice, for nitrate was found in the rice plants at different periods in their growth and was most abundant in the plants fertilized with nitrates. The question in this connection arises, Can ammonia nitrogen fully supply all the nitrogen requirements of rice, and how does this plant behave with nitrates as its only source of nitrogen? The following experiments are of interest in this connection:

Thoroughly leached silica sand free from nitrogen was sterilized by baking over a free flame for several hours and then used in pot experiments. In addition to a general nutritive solution,[1] different forms of nitrogen were applied to different pots. The seedlings were transplanted and treated in every way as the pot experiments already described. Two series were grown, a dry-land and a wet-land series. While sterile solutions and sand were used at the beginning, the facilities at hand did not make it possible to grow the rice under sterile conditions throughout. Consequently it is not impossible that bacterial changes brought about some transformation in the nitrogen

[1] The cultural solutions were prepared according to MacDougal. Text-book of Plant Physiology, New York and London, 1901, pp. 225.

applied. With a view of having a check on such changes it was planned to determine the nitrates, nitrites, and ammonia in these cultures at intervals during the growth, but stress of other work prevented the making of any of these except the determination of nitrites. From some preliminary experiments it is found to be imperative to know the content of nitrites in sand cultures of this sort. The sand used in these experiments was found to contain large quantities of denitrifying bacteria and several methods of sterilization were employed before a thoroughly satisfactory one was found. Unless all the denitrifying bacteria were killed it was found that either nitrates or ammonia became rapidly converted into nitrites, and that in the presence of excessive amounts of nitrites the rice turned yellow, made poor growth, and usually died. Numerous experiments proved that in a concentration of five or more parts of nitrite per million rice becomes seriously injured, and if such concentration is maintained for any considerable length of time the plant will die.

In order, therefore, to know definitely the amount of nitrites present, each culture solution was tested daily, and only such as were found to contain small amounts or no nitrites are recorded. Chemically pure compounds were used in making the culture solutions. In the wet-land series the cultures to which nitrate of soda was added failed to bring about any growth of rice whatever. Repeated trials were made and in every instance the seedling stood for some days, turned yellow, and died. In the trials with other nitrates the seedlings also became yellow, but finally overcame this and developed into fairly normal plants. In each of these instances, however, nitrates seemed to be unable to properly nourish the young seedlings. It was about a month after transplanting before the rice that was fertilized with nitrates made effective growth. In the cultures containing ammonium nitrogen, however, except in the case of ammonium nitrate, the seedlings made vigorous growth from the first. The rice in these was of a deep green color and in every way normal in appearance. The use of ammonium nitrate, however, was not attended with such favorable growth. With this compound the seedlings turned yellow and appeared to be stunted at first, but fairly normal development was made later and, as will be seen from the table, greater yields were obtained than from the use of nitrates alone.

The dry-land series acted in most ways similar to that of the wet-land series, except that nitrates seemed to bring about normal growth earlier than in the wet-land series. The average of the air-dried weights and nitrogen absorbed per pot under the different treatments will be given in the following table:

Yields and nitrogen absorbed in sand culture.

WET-LAND SERIES.

Nitrogen applied.	Straw.	Paddy.	Total.	Nitrogen in— Straw.	Paddy.	Total.
	Grams.	*Grams.*	*Grams.*	*Per ct.*	*Per ct.*	*Grams.*
Calcium nitrate	7.3	3.7	11.0	0.320	0.826	0.0539
Magnesium nitrate	13.3	6.0	19.3	.372	.800	.0975
Ammonium nitrate	15.5	9.0	24.5	.344	.854	.1302
Ammonium phosphate	38.0	16.0	54.0	.329	.980	.2814
Ammonium sulphate [1]	64.0	32.0	96.0	.388	1.028	.5772

DRY-LAND SERIES.

Nitrogen applied.	Straw.	Paddy.	Total.	Nitrogen in— Straw.	Paddy.	Total.
Sodium nitrate	5.6	1.6	7.2	.644	1.276	.0559
Magnesium nitrate	6.3	2.7	9.0	.574	1.248	.0708
Ammonium nitrate	10.0	3.0	13.0	.718	1.416	.1142
Ammonium sulphate	13.0	4.0	17.0	.824	1.366	.1617

[1] The greater growth obtained from the use of ammonium sulphate than from ammonium phosphate is believed to be due mainly to the fact that the ammonium sulphate series was grown in pots of about twice the capacity of those used in the other series. In each instance the cultural solutions were of equal concentration.

DISCUSSION.

The question of why nitrates are not as effective in the nutrition of rice as ammonia has been the subject of some speculation. In 1898, Suzuki [1] concluded from his experiments on the utilization of nitrogen by phanerogams that the presence of certain quantities of sugar is necessary for the transformation of nitrates into asparagin, which he holds is a necessary step in the formation of proteids. On the basis of this investigation Nagaoka [2] concluded that the failure of nitrates in submerged rice culture may in part be due to the accumulation of insufficient quantities of sugar in the leaves. Later Daikuhara and Imaseki [3] pointed out that dry-land rice which responded to the use of nitrate contained no larger quantities of sugar than were found in wet-land rice, and therefore the failure of nitrates could not be attributed in this instance to the lack of sugars in the plant. These investigators attribute the unfavorable action of nitrates in paddy soils to the loss of nitrogen by denitrification, the formation of poisonous nitrites and loss of nitrates through leaching.

In the foregoing experiments it has been shown that serious loss of available nitrogen may follow the use of nitrates in rice soils and also that poisonous nitrites are formed. When the accumulation of nitrites reaches a concentration of about five parts per million the rice turns yellow and may be seriously injured. On the other hand, when denitrification is prevented and no nitrites are formed, young rice seedlings are still unable properly to utilize nitrates. The appearance of the plants indicates a physiological disturbance. They turn

[1] Bul. Col. Agr., Tokyo Imp. Univ., 3 (1898), pp. 488–507. [2] Loc. cit. [3] Loc. cit.

yellow and remain standing for several weeks where nitrates furnish the only source of nitrogen. The percentage of sugar in the leaves, as pointed out above, does not offer sufficient explanation of this phenomenon, for the leaves of young rice seedlings contain rather large percentages of sugar; in fact, similar quantities to that found in the leaves of most cereals.

The conversion of nitrates into proteids is essentially a reduction process. Nitrates as such do not occur to any considerable extent in plants and that which is present in most instances may be looked upon as being unassimilated. Likewise, proteids, derived from whatever source, do not contain nitrogen as an immediate derivative of nitrate, but are more properly looked upon as being made up of the ammonia derivatives. From this point of view it seems that ammonia ought to be more easily assimilated by plants than nitrates, and in fact there are certain evidences that give support to this view. It has been observed by investigators that while ammonia as such does not occur in plants to any considerable extent, their nitrogen content may be considerably greater if ammonium salts are used as fertilizers. Russell and Hutchinson[1] recently found this to be true in their experiments; and the analytical results in previous pages indicate the same.

It seems reasonable, therefore, that while the solubility and free circulation of nitrate in the soil moisture may bring it into more intimate contact with the absorbing surfaces of plants (thus making possible its greater absorption than is ordinarily effected by ammonia), the actual assimilation of nitrogen may be easily accomplished from the ammonia form. In the instance of paddy rice the experiments already described indicate this point. The taking up of nitrates through osmosis can be effected so far as known equally as readily as ammonium salts, but in some way rice appears not to have sufficient power of converting nitrates into proteids, but is abundantly able to transform ammonium salts into these substances.

It has been known for some time that extract from living plants[2] have the power of reducing nitrates into nitrites. This change has been attributed to enzymotic action, and while it may not be necessary in the process of catabolism for nitrates to be changed into nitrites, it is not unlikely that the whole series of changes which nitrogen undergoes in the construction of proteids is in a large measure brought about by enzymotic agents. Natural selection, breeding, and environment are known to have a great influence on plants. May it not be that rice, which having grown for centuries under conditions that largely exclude the formation of nitrates, has in a large measure lost the power of reducing nitrates? Further experiments will be conducted to determine the correctness of this view.

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[1] Loc. cit. Similar results were also obtained by Hutchinson and Miller. Loc. cit.

[2] See Kastle and Elvove. Amer. Chem. Jour., 31 (1904), pp. 606–641.

SUMMARY.

Experiments reported in this bulletin show that in field trials the application of ammonium sulphate produced considerable increases in the yields of straw and grain of rice, while nitrate of soda was ineffective. The application of ammonium sulphate before planting gave greater yields than were produced by applications at intervals during the growth of the crop. Nitrate of soda produced little or no effect, however applied.

In pot experiments with the use of soil the application of nitrates was without effect until near the heading period of the rice. Only small increases in yields were brought about by nitrates when applied before planting the rice. A somewhat greater yield resulted from the use of nitrates applied at intervals in the growth of the crop. Soy-bean cake as an organic form of nitrogen produced considerable increase in the growth, while ammonium sulphate was the most effective of all forms applied. Ammonium sulphate not only increased the height of the rice, but also brought about greater tillering than nitrates, thus insuring a large number of fruiting stems in a given area.

Denitrification was found to take place in paddy soils, thus resulting in the formation of nitrites and possibly bringing about loss of nitrogen as the free gas. Ammonia developed to a considerable extent during the time of irrigation, while the nitrates originally in the soil soon became reduced to a low minimum.

The application of nitrates gave rise to a slight increase in the ammonia of the soil. The addition of soy-bean cake resulted in considerably increased ammonia formation, and still greater quantities of recoverable ammonia occurred where ammonium sulphate was applied. Measureable increases in the ammonia content of the soil were found at the end of one month's growth of the rice, and at this time the ammonia content was still considerably greater in the pots to which ammonium sulphate or organic nitrogen had been applied. Differences of the same order but of unequal magnitude were found in the soil from the field plat experiments two months after the applications were made.

Experiments in flasks prove that denitrification is sufficiently active to account for the loss of nitrates found in pot experiments, and that ammonification takes place to a considerable extent in submerged rice soil.

Sand cultures resulted in showing that, if rice has access to nitrates as the only source of combined nitrogen, unhealthy and stunted growth follows, while on the other hand ammonium salts brought about vigorous growth and in every way normal-appearing plants.

In practice the use of ammonium salts or organic nitrogen and not nitrates are recommended for rice culture.

The more nitrates there are in rice soils the greater will be the quantity of nitrites formed, and if nitrites accumulate to any considerable extent injury to rice will result.

The failure of rice to properly assimilate nitrates can not be adequately explained on the basis of insufficient sugar content in the leaves, but may be due to a lack of nitrate-reducing enzyms, which, having long ceased to function through nonuse, are no longer developed in sufficient quantities to enable the rice plant to fully satisfy its nitrogen requirements.

Credit is due and thanks are here extended to Mr. F. G. Krauss for cooperation in this work and to Mr. William T. McGeorge for the determination of the nitrogen in the paddy and straw.

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HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 26.

THE FUNCTION AND DISTRIBUTION OF MANGANESE IN PLANTS AND SOILS.

BY

W. P. KELLEY,

Chemist.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

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[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *October 12, 1911.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 26 of the Hawaii Agricultural Experiment Station a paper dealing with The Function and Distribution of Manganese in Plants and Soils, by W. P. Kelley, chemist of the station. For three years the station has been investigating the soil conditions in the chief pineapple districts of the Territory with special reference to getting satisfactory growth of pineapples in certain localized areas. The cause of the poor growth of pineapples in these areas is found to be the manganese in the soil. This element occurs in much higher percentages than have heretofore been reported in other countries. The paper contains an account of the peculiar distribution of manganese, the chemical and physical forms under which it occurs, its apparent origin from the lava rock, and the peculiar effects which it exercises upon pineapples and other plants. The whole problem presented by the occurrence of a high percentage of manganese in soils has been investigated, and important steps in advance have been taken on various parts of the field of investigation. The paper is therefore a decided contribution to the literature of this comparatively new field.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

CONTENTS.

THE FUNCTION AND DISTRIBUTION OF MANGANESE IN PLANTS AND SOILS.

THE FUNCTION OF MANGANESE IN PLANT GROWTH.[1]

INTRODUCTION.

The rôle played by the several elements that occur in plants is a subject of much interest, and one that has been investigated for many years. For about a century it has been recognized that mineral substances are essential in the normal growth and development of plants, and are connected in some vital way with the phenomena of life. In addition to the elements essential to growth there are others found to a greater or less extent in all soils.

Growing plants have the power of absorbing these accessory substances to a considerable extent, but in general the occurrence of small amounts of such elements in plants has been looked upon as being somewhat accidental. The soil moisture dissolves various chemical substances which by osmosis pass into plant sap, and thus ultimately find their way to the several plant organs. The occurrence of small amounts of certain elements in plants, therefore, has been considered as having no special significance.

While it is well known that only about 10 elements are essential to the normal growth and reproduction of the higher plants, certain observations and experiments in recent times suggest that at least some of the accessory and supposedly unnecessary elements that occur in plants may perform some useful function in the economy of nature.

Inquiry has arisen concerning the explanation of the fact, for instance, that while iodin occurs as a minor constituent of sea water, certain marine plants have the power of storing up in their tissues relatively large quantities of this element. Similarly, chlorin [2] occurs to the extent of not more than 0.01 per cent of ordinary soils (in many cases even less), but some plants have the power of extracting this element in rather large amounts. Instances are known where the soil contains only a trace of chlorin and yet some plants absorb from it more chlorin than phosphorus, an element universally considered to be necessary to plant growth. The same may be said in reference to the occurrence and absorption of manganese.

[1] Presented to the faculty of the graduate school of the University of California in partial fulfillment of the requirements for the degree of doctor of philosophy, September, 1911.

[2] Chlorin is considered by some authorities to be essential to the growth of plants.

Hilgard [1] as early as 1860 pointed out that the ash of the long-leaf pine from Mississippi contains in some instances a relatively large percentage of manganese.

In 1878 J. Schroeder [2] reported the ash of the Norway spruce, *Picea excelsa*, to contain 35.53 per cent Mn_3O_4 in the case of the needles, and 41.23 per cent in that of the bark, and while he did not report the per cent of manganese in the soil, it is safe to conclude that the amounts present were small; so far as is known, highly manganiferous soils do not occur in that region.

THE OCCURRENCE OF MANGANESE IN PLANTS.

The earliest record reporting the occurrence of manganese in plants is furnished us by Scheele,[3] who pointed out that the ash of the seed of the wild anise contains a small amount of manganese, while a considerably larger portion occurs in the stems of the same plant. Herapath,[4] in 1849, determined the presence of manganese in the ash of the radish, beet, and carrot; and according to the same authority, Richardson found it to be present in the ash of sugar cane. In the same year Salm-Hortsmar [5] reported manganese as occurring in the ash of oats. In 1851 Liebig [6] found that tea contained manganese. By evaporating an infusion to dryness and igniting the residue a green ash was obtained, which color Liebig attributed to the presence of manganate of potassium. In 1872 Leclerc [7] published analyses of various plants and soils and concluded from his investigations that manganese is a universal constituent of soils and likewise occurs in the ash of most plants. From his researches it would appear that certain forest trees, particularly the firs, birches, and elms contain rather large amounts of manganese, while the herbaceous plants contain it only in small amounts. In the various soils analyzed he found manganese in every instance, although none was found which contained more than a few tenths of 1 per cent. In 1884 Maumené[8] pointed out that the parenchyma of cabbage leaves contains only a trace of manganese, while the veins contain considerable quantities.

Special interest in this question was not aroused, however, until late in the nineteenth century. As a result of some investigations on the latex of the lac tree, *Rhus succedanea*, Bertrand [9] pointed out that the ash of oxidizing enzyms contains manganese. The latex was found to contain two substances which he designated as laccase and

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[1] Rpt. Geol. and Agr. Miss., 1860, p. 360.
[2] Tharand. Forstl. Jahrb. Sup. I (1878), p. 97; Jahresber. Agr. Chem., 21 (1878), p. 110.
[3] Mémoires de Chymie. Dijon, 1785.
[4] Cited by Rousset, Ann. Sci. Agron., 3. ser., 4 (1909), II, p. 82.
[5] Jour. Prakt. Chem., 46 (1849), p. 193.
[6] Familiar Letters on Chemistry. London, 1851, 3. ed., pp. 458, 459.
[7] Compt. Rend. Acad. Sci. [Paris], 75 (1872), p. 1213.
[8] Compt. Rend. Acad. Sci. [Paris], 98 (1884), p. 1418.
[9] Rev. Gén. Chim., 8 (1905), pp. 213, 214.

laccol. The dark color which is developed in the latex upon its coming in contact with air he found to be due to a change in the laccol, brought about by oxidation, the laccase acting as an oxygen carrier. Laccase, therefore being an oxidizing enzym, is able to effect the oxidation of a large amount of laccol. The phenomenon of autooxidation is by no means confined to the lac tree, but is a general property in varying degrees in plants. The most highly purified oxidase from various sources upon incineration, Bertrand found to contain manganese. In the following year he showed that by the addition of manganese compounds to the oxidases their oxygen carrying power was, within certain limits, increased in proportion to the amount of manganese present. Following this discovery it was soon suspected that the manganese performs some physiological function in the vegetable kingdom, and numerous experiments with the use of various compounds of this metal have since been made.

PREVIOUS INVESTIGATIONS.

EXPERIMENTS WITH MANGANESE.

Historical.—The artificial application of various manganese compounds in soil and culture experiments has given widely differing results. In a large number of cases increased growth with a variety of different plants has resulted. In a number of instances, however, negative results have been obtained, while in certain cases a pronounced toxic effect has been observed.

In 1899 Giglioli [1] applied manganese dioxid at the rate of 1.14 quintals per hectare (about 102 pounds per acre) in some wheat experiments and found in some instances it resulted in an increase, while in others a decrease in yield occurred.

Loew and Sawa [2] in 1903 found that by the addition of small amounts of manganese sulphate to culture solutions a considerable increase in the growth of barley, rice, cabbage, beans, and peas was effected. They also made similar applications to soils in pot experiments and with similar results. In the same year Aso [3] cultivated barley, radishes, wheat, and peas in culture solutions containing manganese sulphate and concluded that in sufficiently dilute solutions manganese exerts a stimulating effect.

Nagaoka [4] applied manganese sulphate in addition to a general fertilizer to soils in boxes, in which he grew rice and obtained approximately one-third increase in the yield. The increased growth of the rice was found to be proportional to the manganese applied up to the

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[1] Ann. R. Scuola Sup. Agr., Portici, 2. ser., 2 (1901), p. 133; Centbl. Agr. Chem., 31 (1902), No. 3, p. 206.
[2] Bul. Col. Agr. Tokyo Imp. Univ., 5 (1902–3), pp. 161–172.
[3] Bul. Col. Agr. Tokyo Imp. Univ., 5 (1902–3), pp. 177–185.
[4] Bul. Col. Agr. Tokyo Imp. Univ., 5 (1902–3), pp. 467–472.

amount of 25 kilograms of Mn_2O_3 per hectare, while larger applications brought about practically the same yields. The following year [1] these experiments were continued without any further application, and an increased production of 16.9 per cent resulted. The third year Nagaoka [2] continued these experiments by applying manganese sulphate, chlorid, and carbonate. While the season is reported to have been very unfavorable for the growth of rice, it is significant that in most instances a decrease in yield was obtained. The fact that increased growth had been obtained the two previous years by the application of manganese, the author suggested may have partially exhausted the available plant food, so as to bring about need for a general fertilizer. Nagaoka also suggested that the repeated applications of manganese salts probably produced an acid condition in the soil.

Voelcker [3] in some pot experiments at the Woburn Experiment Station found that a decrease in the growth of wheat and barley followed the application of manganous iodid, while the nitrate and phosphate produced a stimulating effect. Germination and sprouting were retarded by manganese dioxid and sulphate, while a deeper green and more luxuriant growth were obtained from the use of manganous chlorid.

In 1904, Loew and Honda [4] obtained from the use of manganese sulphate a noteworthy increase in the growth of the tree *Cryptomeria japonica*.

Bertrand and Thomassin [5] in 1905 grew oats in a soil containing 0.057 per cent manganese, of which 0.02 per cent was soluble in acetic acid and found that by the application of manganese sulphate a considerable increase in growth was obtained. The general appearance of the treated and untreated plats was very similar at harvest time, but notable differences in yields were obtained. The same year Salomone [6] pointed out that by the use of manganese dioxid considerable increases in the yield of wheat were produced; and in 1907 [7] by the use of various compounds of manganese he again obtained considerable increases in the yields of wheat, beans, oats, and onions, always provided, however, the manganese was not applied in too great quantities.

Bertrand [8] further obtained a considerable increase in the yield of oats by the use of manganese sulphate, but found that the oats did not absorb an additional amount of manganese.

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[1] Bul. Col. Agr. Tokyo Imp. Univ., 6 (1904–5), pp. 135, 136.
[2] Bul. Col. Agr. Tokyo Imp. Univ., 7 (1906), pp. 77–81.
[3] Jour. Roy. Agr. Soc. England, 64 (1903), p. 348; 65 (1904), p. 306.
[4] Bul. Col. Agr. Tokyo Imp. Univ., 6 (1904–5), pp. 125–130.
[5] Compt. Rend. Acad. Sci. [Paris], 141 (1905), p. 1256.
[6] Staz. Sper. Agr. Ital., 38 (1905), pp. 1015–1024.
[7] Staz. Sper. Agr. Ital., 40 (1907), pp. 97–117.
[8] Compt. Rend. Acad. Sci. [Paris], 141 (1905), p. 1255.

Katayama[1] in 1906 applied a solution containing 0.01 per cent of manganese sulphate as a top dressing, at intervals of about 6 weeks, during the growth of barley, and obtained a slight increase in yield, while more concentrated solutions effectively retarded the growth. Further experiments on the stimulating effects of manganese chlorid on rice were made during this year by Aso,[2] which resulted in showing a slight increase in yield, although of less magnitude than had been observed in former years. Where the manganese was used in addition to a liberal application of other fertilizers, scarcely any effects were produced, while with soils which had been continuously cultivated without a general manure it gave an increase of 23.5 per cent. Summing up the results, Aso states: "On the manganese plats the increase was relatively greatest where the manuring conditions were least favorable." The increases in total harvest for the four years over which these experiments were conducted were as follows: 1903, 41.8 per cent; 1904, 2.2 per cent; 1905, 3.5 per cent, and 1906, 23.5 per cent, without a general fertilizer. With a complete manure no increase was obtained.

In 1907, Molinari and Ligot[3] conducted a series of pot experiments with oats, using soil containing from 0.01 to 0.07 per cent manganese. In addition to a complete fertilizer manganese sulphate was applied in quantities of from 0.05 to 0.20 gram per pot. The maximum increase in yield was obtained by the application of 0.10 gram per pot, while the use of larger quantities produced only slight increases in yield. Some experiments have been made by Belgian agronomists with sugar beets, the results of which are of interest in this connection. Grégoire, Hendrick, and Carpiaux,[4] in addition to a general fertilizer, applied manganese sulphate at the rate of 10 and 50 kilograms per hectare and found that in each instance a decrease in total weight of the beets was obtained. The sugar content, however, was slightly greater where manganese had been applied, so that the total yield of sugar was practically the same in each instance. Garola,[5] at the experiment station in Chartres, on the other hand, obtained notable increases in the yield of beets by the application of 3.5 grams of manganese per square meter applied as chlorid and sulphate. According to Rousset,[6] experiments with beets made in Bohemia by Stoklasa resulted in producing an increase of 15 to 20 per cent by the use of manganese compounds, while Gillin reported a decrease in yield from the use of manganese carbonate, although the percentage of sugar in the beets was augmented.

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[1] Bul. Col. Agr. Tokyo Imp. Univ., 7 (1906), pp. 90–93.

[2] Bul. Col. Agr. Tokyo Imp. Univ., 7 (1907), pp. 449–453.

[3] Bul. Agr. [Brussels], 23 (1907), p. 764.

[4] Ibid., p. 388.

[5] Cited by Rousset, loc. cit.

[6] Ann. Sci. Agron., 3. ser., 4 (1909), II, pp. 81–111.

Feilitzen [1] cultivated oats on a moor soil poor in the elements of plant food, to which a general fertilizer was applied in addition to manganese sulphate at the rate of 10 kilograms per hectare, but he failed to obtain any increase in the yield. Grégoire, Hendrick, and Carpiaux [2] also made some experiments with potatoes on a soil very rich in plant food and found that the application of 10 kilograms of manganous sulphate per hectare produced but little effect, while the application of 50 kilograms per hectare brought about a small increase.

In pot experiments in 1908, Garola [3] obtained very large increases in the yield of flax from the use of 1.9 grams of manganous sulphate per pot in one series and 1 gram of manganous chlorid in another. Each pot previously received an application of a general fertilizer, but the increases in yield due to manganese were very great. A similar set of experiments with beans, however, failed to reveal any effect from the addition of manganese.

Sutherst [4] made some pot experiments with corn on a soil from Transvaal, and found that notable increases in the yield followed the application of manganese sulphate, chlorid, or dioxid. The author concluded that manganese exerts a tonic effect, and it is of interest that manganese dioxid stimulated the growth to a greater degree than did the sulphate or chlorid.

Various experiments have been reported from central France,[5] the results of which are by no means concordant. In a number of these tests by-products from certain manganese mines have been applied. These usually contain a mixture of various substances, of such nature that it is difficult to know which constituent is the active one. In certain instances considerable increases in the yields of grapes have been obtained, while in others a decrease was reported.

Malpeaux succeeded in considerably increasing the yield of barley by the use of manganese sulphate, while a similar application produced no effects on oats. Albouy failed to obtain a fertilizing effect in cultures of either wheat or oats. In certain other experiments made under the direction of Marre results uncertain and sometimes contradictory were obtained.

Bernardini [6] in 1910 published a series of experiments, the results of which show that considerable increases in the yield of corn and wheat were obtained by the use of manganese chlorid, and Strampelli [7] reported considerable increases in the yields of various grains from the use of manganese sulphate, carbonate, and dioxid.

[1] Jour. Landw., 55 (1907), pp. 289–292.
[2] Loc. cit.
[3] Cited by Rousset, loc. cit.
[4] Transvaal Agr. Jour., 6 (1907–8), p. 437.
[5] Rousset, loc. cit.
[6] Staz. Sper. Agr. Ital., 43 (1910) pp. 217–240.
[7] Atti 6. Cong. Internaz. Chim. Appl., 4 (1906), pp. 14–17.

In 1910 Bartmann[1] discussed some experiments in which manganese was applied as the chlorid, sulphate, carbonate, dioxid, and two products from manganese mines which consist primarily in a mixture of Mn_2O_3 and Mn_3O_4. Beets, peas, and beans were considerably increased in yield by the carbonate and the manganese mine products. The dioxid, chlorid, and sulphate had but little effect. In a second set of experiments the growth of corn was shown to be stimulated by the application of manganese, from 200 to 400 kilograms per hectare being found to give the maximum effect. Similar amounts appeared to reduce the yields of both potatoes and beets.

From the foregoing experiments the value of manganese as a fertilizer can not be considered as having been established. It is true increased growth in a number of instances has resulted from the application of various manganese compounds, but on the other hand either no effects or a retardation in growth has been reported in so many instances that manganese as a practical fertilizer can not be recommended. In most instances the publications dealing with this subject do not give sufficient data concerning the composition and types of soils used to enable the reader to adequately correlate the effects produced. There is considerable evidence, as will be shown later, however, that the stimulating effects reported were in a large measure due to indirect action. From the experiments in water cultures, on the other hand, there is little doubt of a stimulating effect if manganese be employed in sufficient dilution.

PHYSIOLOGICAL EFFECTS OF MANGANESE.

Historical.—The discovery of the occurrence of manganese in plants naturally suggests the possibility of this element playing some physiological part. Manganese and iron are closely related from a chemical standpoint; they have many properties in common and enter into many similar reactions. This similarity suggested the possibility of substituting manganese for iron in culture solutions. Iron having been known for a long time to be connected in some way with the production of chlorophyll, the first experimental observations with manganese in plant cultures were made with reference to the green coloring matter.

Sachs[2] in 1865, attempted to substitute manganese for iron in the nutrition of various plants, but failed of success. The leaves of the plants became yellow and etiolated.

Birner and Lucanus[3] pointed out that manganese can not replace iron in the production of chlorophyll, and Wagner found that while

[1] Jour. Agr. Prat., n. ser., 20 (1910), No. 47, p. 666.

[2] Handbuch der Experimental-Physiologie der Pflanzen. Leipzig, 1865, p. 144.

[3] Landw. Vers. Stat., 8 (1866), pp. 128–177.

the amount of iron in plants is often less than that of manganese, manganous and manganic phosphates suspended in culture solutions can exert an injurious effect. Field experiments have since shown, however, that sometimes plants take on a deeper green and become more thrifty in appearance following the addition of manganese to the soil. This has been especially noted in cases where stimulated growth has resulted from the application of this element.

In 1884, Maumené[1] found that the ash from the parenchyma of cabbage leaves was white and infusible and did not contain a trace of manganese, while the ash from the veins of the same plant was very fusible and contained manganese in considerable amounts. He also found similar differences in wheat. This author concluded that the larger part of manganese existed as a salt of an organic acid, and that it is only in the sap that manganese occurs.

Following the discovery that manganese occurs in the ash of oxidases, Bertrand[2] found that by the addition of certain soluble salts of manganese to various oxidases, the oxidation of a solution of hydroquinone in a given length of time was proportional to the amount of manganese present. On account of his inability to completely separate the oxidases from manganese, together with the effects produced by the addition of manganese compounds to the sap of lucern, he was led to look upon manganese as being in some way connected with the phenomenon of oxidation in plants. He showed that their oxidizing activity could be considerably increased by the addition of manganese compounds. Not all the salts of manganese possessed this power in equal degrees. The degree of the increased oxygen-carrying power of oxidases under the influence of manganese salts, Bertrand found to be inversely proportional to their degree of dissociation, the nitrate, sulphate, and chlorid being much less active than the acetate, salicylate, and succinate.

Pichard,[3] in 1898 determined the presence of manganese in a large number of plants, and found it to occur in greatest concentration in the leaves and active growing parts. He also found it to be deposited to a considerable extent in the reproductive organs.

In 1901 Coupin[4] found that various chemical substances if present in sufficient concentrations may be toxic to plants. With manganese as nitrate a concentration of one part in 13,000 proved to be toxic to the germination of wheat, and considerably hindered the rate of germination. From some experiments on the oxidases, Trillat[5] found that manganese acts catalytically, and by the addition of a

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[1] Loc. cit.

[2] Compt. Rend. Acad. Sci. [Paris], 124 (1897), pp. 1032, 1355.

[3] Compt. Rend. Acad. Sci. [Paris], 126 (1898), p. 1882.

[4] Compt. Rend. Acad. Sci. [Paris], 132 (1901), p. 645.

[5] Compt. Rend. Acad. Sci. [Paris], 138 (1904), p. 274.

small amount of soluble manganese to the oxidases an increase in their oxygen-carrying power takes place.

At the summer meeting of the American Chemical Society in 1902, Ewell [1] read a paper in which he discussed a soil on which leguminous crops had failed. An aqueous extract of this soil was found to contain about twice as much manganese as calcium, and the legume failure was suspected of being due to the manganese. No further investigation of the question has been reported.

At the meeting of the International Congress of Applied Chemistry in Berlin in 1903, Bertrand [2] read a paper in which he pointed out that in addition to the principal elements that are found in plants, there exist rarer elements which usually occur in small amounts in plants, and that they may perform some physiological function. In this connection he proposed to call such compounds "Supplemental manures" (*Engrais Complementaires*).

In 1903, Loew and Sawa [3] published the results of a number of experiments in water cultures with young pea plants, barley, soy beans, rice, and cabbage. They found that the pea plants in solutions containing 0.25 per cent manganese sulphate were seriously injured in 5 days. The leaves lost their turgor, dried up, and no trace of new rootlets was to be observed. In a 0.1 per cent solution of the same salt, barley seedlings were injured slightly. After 7 days a fading of the green to a yellow was noted; and some water rootlets were developed, although much fewer than in the control. On the ninth day portions of the leaves showed a more pronounced oxidizing enzym reaction than was obtained from the control plants. The increased activity of the oxidizing enzyms, they think, may account for the fading of the green color.[4] In nutrient solutions containing 0.02 per cent manganese sulphate they grew barley and soy beans, and again observed a yellowing of the plants. Subsequent experiments, however, convinced them that if the weather be sufficiently warm, and the manganese present in sufficient dilution a stimulation takes place and no yellowing is produced. With rice seedlings in pots containing 8 kilograms of soil to which 200 cubic centimeters of a 0.1 per cent solution of manganese sulphate was added a stimulating effect was produced; and similar results are recorded with the use of peas and cabbage in soil cultures.

Discussing these results, the authors make the following interesting statements:

Now it is well known that light retards growth. This hitherto unexplained phenomenon forms a strong contrast to the chemical work the light performs with the aid

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[1] Science, n. ser., 16 (1902), p. 291.

[2] Cited by Loew, Bul. Col. Agr. Tokyo Imp. Univ., 6 (1904–5), p. 161.

[3] Loc. cit.

[4] See Woods, Centbl. Bakt. [etc.], 2. Abt., 5 (1899) p. 745.

of the protoplasm in the chlorophyll bodies. One and the same agency, then, increases the organic food, on the one hand, and suspends the utilization of that food on the other. It is in the absence of light that growth proceeds and the products of the sun's work are chiefly consumed. The absence of light has, therefore, the same effect as the presence of manganese. It seems as if under both of these conditions a check is removed which the sun's rays exert. This check might be due to the action of certain noxious compounds produced in the cells under the influence of light. Such compounds are frequently produced in the course of metabolism.[1] It is the office of the oxidizing enzyms, as one of us has suggested, to destroy noxious by-products of the benzene series—a view verbally expressed as follows: "The writer's view on this subject[2] is that as the living protoplasm can oxidize carbohydrates and fat, but does not attack, or attacks with difficulty, compounds of the benzene group; and, on the other hand, as just the opposite takes place with the oxidizing enzyms, it may be inferred that there exists between the protoplasm and the oxidizing enzyms a certain division of labor, the former oxidizing the compounds of the methane series, and the latter those of the benzene series. The former provides for the kinetic energy of the cells; the latter destroys, by partial oxidation, noxious by-products. The oxidations in the former case are generally complete, but in the latter, only partial."

Loew and Sawa summarize their findings as follows:[3]

> Manganese exerts, in moderate quantity, an injurious action on plants, consisting in the bleaching out of the chlorophyll. The juices of such plants show more intense reactions for oxidase and peroxidase than the healthy control plants. Manganese exerts, further, a promoting effect on the development, still observable in high dilution, while the injurious effects disappear under these conditions. It is probable that soils of great natural fertility contain manganese in an easily absorbable condition and that this forms one of the characteristics of such soils.

Aso[3] found that extracts from the leaves of radishes grown in culture solutions containing manganese also contained a more active oxidase than similar leaves from the control plants. In the case of barley grown in culture solutions containing manganous sulphate a yellowing of the leaves was noticed, and the roots gradually turned brown; also the lower leaves turned brown, especially in spots. Microscopic examination of the epidermal cells showed a browning of the nuclei and colorimetric tests for oxidizing enzyms also gave stronger reactions than were obtained from the green leaves of plants not fertilized with manganese. Similar observations were made with wheat; the lower leaves turned brown, as also did the roots, which in this case the author found to be due to manganese dioxid adhering to the roots. The yellowing of these plants suggested an interference in the assimilation of iron, and in order to provide against this possibility, ferrous sulphate was added to parallel cultures containing manganese, with the result that a partial, although not complete, counteracting of the yellowing was produced. On account of the stimulating effect of small amounts of manganese in field experiments, thus enabling the crop to absorb larger amounts

[1] Reinitzer, Ber. Deut. Bot. Gesell., 11 (1893), p. 531.
[2] U. S. Dept. Agr. Rpt. 59, 1899, p. 27.
[3] Loc. cit.

of the essential elements, Loew [1] suggested that its use would ultimately result in a depletion of the soil unless a general fertilizer was also applied. He cited experiments which may be taken as an indication of some indirect effect of the manganese on other substances in the soil. As already mentioned, Aso attributes a part of the residual effects of the treatment with manganese to a possible accumulation of acidity in the soil.

In a series of culture experiments with wheat, Voelcker [1] found that a deeper green color was produced by the application of manganous chlorid, while a retardation in germination followed the use of manganous iodid. The latter salt was also found to greatly hinder root development, small delicate roots with few rootlets being formed. In the solutions containing manganous sulphate good root development took place, although the root hairs were found to be smaller in size than in the check solutions. In a number of these experiments the roots at maturity were observed to be coated with a thin film of manganese dioxid.

In a series of experiments in 1905 Salomone [2] pointed out that injury to the germination of rape and cabbage followed their soaking in dilute solutions of manganous fluorid or iodid. He grew beans in sand cultures to which dilute solutions of these salts were added, and found an increased chlorophyll production and a consequent fertilizing action. With spring wheat, similar cultures resulted in showing a stimulating effect; but when the dose was increased about 50 kilograms per hectare a falling off was observed and maturity delayed.

In 1907 the same author [3] published an exhaustive series of experiments in which he observed that certain manganese compounds exercised a stimulating effect, whereas others produced a toxic effect. By the use of a highly calcareous clay, he grew wheat in field experiments, using dilute solutions of manganese as the iodid, fluorid, nitrate, sulphate, chlorid, and the various oxids. With the oxids the leaves turned slightly yellow and maturity was hastened from four to seven days. The final yield, however, was increased, and there was an increase in the nitrogen content of the grain. By increasing the application of manganese as manganous sulphate, above 50 kilograms per hectare, he observed a decided depressing effect, and when still greater quantities were applied the plants died. The grain from all the treated plats contained a larger quantity of manganese than from the check plats, and increased with the larger applications. Where manganese exerted a toxic effect, when applied in large doses it caused a breaking up of the plasma in the meristem tissues. The growing tips turned yellow and finally died. Plasmolysis ensued in

[1] Loc. cit.

[2] Staz. Sper. Agr. Ital., 38 (1905), pp. 1015–1024.

[3] Ibid., 40 (1907), pp. 97–117.

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the epidermis and central cylinder of the roots. The protoplasmic vesicles became separated from the cell walls for a distance of about two-thirds of their circumference. Plasmolysis also accrued in the bark and pith of the roots, which were found to be brown in color. The protoplasm drew away from the cell walls and the nuclei became brown. Starch and aleurone grains were less numerous than in the check plants. The protoplasm was altered in some way, as shown by the Millon reaction, which did not give its usual rose-red color. Wheat was grown a second time on the same plats and again a toxic effect was observed, and it was found that the application of lime and basic slag did not diminish this toxic effect.

With beans grown in boxes Salomone found that various manganese compounds, in quantities up to 40 kilograms per hectare, produced stimulation, whereas the application of more than 60 kilograms per hectare caused the plants to die. He found that the toxic effect was slightest when the manganese functioned as an electropositive element and increased in passing from manganous through manganic to permanganic compounds; in other words, when manganese functioned as an electro-negative element it was more toxic than when an electro-positive element. With oats in field experiments, he also observed an increase in the percentage of nitrogen in the grain where manganese was applied. In other experiments with leeks and onions, the use of manganese dioxid at the rate of 1.5 grams of manganese per square meter produced an increased growth. Manganous sulphate at the rate of 1 gram of manganese per square meter resulted in producing a darker green color when applied to meadows, as well as increasing the total yield.

In summarizing these results Salomone concluded that the greatest concentration of the manganese is found in the reproductive organs of the plant. The ash of beans and wheat increased in passing from the roots, through the stems and leaves, to the fruit; and in the top of the stems a greater quantity was deposited than lower down. In the seeds the greatest concentration was found in the embryo. Analyses of different portions of the plant at different stages of growth showed that manganese occurs in the roots, stems, and vegetative portions to a greater extent during the early growth than at maturity; and, therefore, he concluded that it migrates to the grain in a way very similar to the translocation of nitrogen and phosphoric acid in the ripening of grains.

The chemical analogy between manganese and iron suggested to Salomone that the former is probably combined in a weak organic combination. In peas, horse beans, rice, corn, chestnuts, rye, mushrooms, etc., he found manganese to exist in two states: (1) As concretions which he supposed to be formed from the cell sap, in which

the manganese was previously observed and (2) in combination with other substances in solution. By macerating these plants with water, he was able to demonstrate its presence in both the solution and the insoluble residue.

Hall [1] holds to the view that the stimulating effect of manganese in field experiments is probably to be explained on the basis of an indirect effect on the dormant bases of the soil, rather than by a direct physiological action, although he considers that the point has not been proven.

In 1909 Guthrie and Cohen [2] described the appearance and subsequent failure of certain crops in Australia, particularly barley and wheat, and concluded that the failure was due to the presence of small amounts of very soluble manganese in the soil.

In 1910 Bernardini [3] published the results of a series of experiments with the use of various manganese compounds, and concluded that manganese acts catalytically on soils increasing their oxygen absorbing power and possibly affecting the soil bacteria. He pointed out that in field trials different manganese compounds frequently bring about increased harvests, although in some instances, negative results have been obtained. He studied the effects of N/5 solutions of sodium, potassium, ammonium and manganous chlorids on soils; and while a certain portion of each of these substances became fixed by the soil, the solution of manganous chlorid had the power of replacing calcium and magnesium from certain silicates to a far greater extent than the other chlorids. He also found that the manganese solution still has the power of replacing the alkaline earths after the soil had been heated for a considerable period, from which he argues that its reaction is in connection with the noncolloidal substances of the soil. He extracted volcanic ash from Vesuvius, mineral hornblende and augite for a period of five days and found in each instance that more lime and magnesia were replaced by the use of the manganese chlorid solution than by the use of the other chlorids. From these results Bernardini concluded that probably the beneficial effects of manganese from artificial applications may be attributed wholly to its indirect effect upon other constituents of the soil rather than its acting physiologically on the plant; and he suggests that a closer examination of the soils previously used in manganese experiments would probably reveal the fact that in those instances where failure has been recorded, the soil will be found to contain large amounts of calcium and magnesium in available forms, perhaps either as the carbonate or in zeolitic combinations.

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[1] Ann. Rpts. Prog. Chem. [London], 4 (1907), pp. 271–272.

[2] Jour. and Proc. Roy. Soc. N. S. Wales, 43 (1909), pp. 354–360.

[3] Loc. cit.

Recently, Brenchley [1] made a series of water cultures with varying amounts of manganese sulphate. In solutions containing one part in 10,000 the roots of barley turned brown, which she supposed to be due to the deposition of manganese oxid; the leaves gave indication of being diseased and also turned brown and finally died. In dilutions of one in 100,000 parts the effects were less noticeable, while concentrations of less than one part per million produced a stimulating effect. Microscopic examinations showed the affected leaves to be made up of cells of normal size and shape, but with brown cell walls. The dead cells occurred at first in patches which later spread over the entire leaf. The presence of manganese in the leaves was determined by fusion with sodium carbonate and potassium nitrate. Brenchley reported that the time of ripening was retarded especially where the manganese was used in greatest concentration. Toward maturity the manganese appeared to be deposited on the surface of the leaves.

DISCUSSION.

From the foregoing experiments positive conclusions regarding the rôle that manganese plays in plant growth can not be drawn. It seems well established, however, that the addition of small amounts of this element may bring about considerably increased growth, whereas the application of larger quantities is attended by physiological disturbances. From the field experiments there seem to be two well-established facts: First, the addition of various compounds of manganese to certain soils results in stimulating plant growth, whereas similar applications to other soils are without noticeable effects; second, some species of plants are more susceptible to the influence of manganese than others.

From the work of Bertrand, manganese appears to be a necessary constituent of the oxidizing enzyms, although more recent investigations have shown that it is not an absolutely essential element in oxidases.[2] Carefully purified oxidases from several sources have been obtained which did not contain a trace of manganese. There is little doubt, however, that manganese usually occurs as a normal constituent of the oxidizing enzyms; and it has been shown by various investigators that the addition of small amounts of soluble manganese compounds to the oxidases and peroxidases greatly accelerates their oxygen-carrying power. The observations of Bertrand, followed by the work of Loew and his coworkers in Japan; also by Giglioli and Bernardini in Italy, that manganese acts catalytically, stimulating the oxidizing activities of plants, as well as enhancing

[1] Ann. Bot. [London], 24 (1910), pp. 571-583.

[2] A very complete review of the literature dealing with the oxidases is given by Kastle, Pub. Health and Mar. Hosp. Serv. U. S., Hyg. Lab. Bul. 59.

the oxidations of the soil,[1] no doubt have an important bearing on this question; but, as Bernardini pointed out, it has not been shown in field experiments that manganese does not react indirectly on other constituents of the soil, and hence it is unjustifiable to conclude that the entire effect is due to accelerated oxidations.

In practically all of the foregoing experiments, artificial cultures, or the application of manganese compounds to soils, have been made. It is generally recognized that the soil is extremely complex, made up of numerous chemical substances, both organic and inorganic, and contains many species of bacteria and other forms of organized life. It is constantly undergoing chemical changes and may therefore be looked upon as being in a state of semistable equilibrium. The addition of any soluble substance necessarily sets in motion reactions and changes, the exact nature of which, due to the complexity of the soils involved, is extremely difficult to comprehend. The addition of a soluble salt will undoubtedly modify the relative concentrations of the several elements in solution in the soil moisture and will more than likely produce important changes in the biological and physical factors of the soil. In addition, many substances are known to have a "replacing effect," that is, they have the power of setting free other elements which are bound up in less soluble combinations, themselves entering into the less soluble combinations, while still other substances become fixed.

It has been conclusively shown in water cultures that modifications in nutritive solutions, of the order previously referred to in this paper, may be attended by various physiological disturbances, the exact nature of which varies from species to species, and it is by no means the same with equal concentrations of all substances. Consequently the effects produced on crops by the artificial application of chemical substances to soils are extremely difficult to interpret. In previous manganese studies artificial applications have been necessary for the reason that natural soils, containing considerable quantities of manganese, have been unknown.

In some investigations on the pineapple soils of Oahu in 1908[2] it was found that this island contains considerable areas which are characterized by abnormally high percentages of manganese. Soils were discovered which contain manganese in varying amounts from less than 0.1 per cent to as high as 9.74 per cent. Subsequently it has been found that the extent of such soils is relatively great. There is offered here, therefore, a natural soil, which has arisen by the operation of natural causes and which contains manganese as an

[1] Roussel suggests that possibly manganese brings about a decomposition of the toxins of the soil. Loc. cit. Recently Schreiner, Sullivan, and Reid in discussing the action of manganese on soils point out that its office is probably associated with oxidation in soils. (U. S. Dept. Agr., Bur. Soils Bul. 73.)

[2] Hawaii Sta. Press Bul. 23; Jour. Indus. and Engin. Chem., 1 (1909), p. 533.

important constituent. By the use of these soils secondary reactions, due to the introduction of soluble manganese compounds, changes in the concentration of the soil moisture due to the addition of a more soluble substance, and the replacing effects attendant thereto will be obviated. All the experiments and observations hereafter to be reported in this paper were made on these soils without the artificial addition of any substance whatever. Most of the plants have been grown in field cultures under usual field conditions. A series of experiments in pots, using the more highly manganiferous soil and a normal soil for comparison, has also been conducted.

FIELD OBSERVATIONS ON MANGANIFEROUS SOILS.

PINEAPPLES.

The chief crop grown on the manganiferous soils of Oahu is pineapples, and the general appearance and physiological features of the plants are characteristic and clearly differentiate them from pineapples on normal soils. The most pronounced characteristic in these plants is an intense yellowish-white appearance in the leaves, which may appear at any period in the growth, although it usually becomes more intense at from 3 to 6 months after the time of planting, and is always most noticeable during the winter months. The pineapple requires about 18 months from the time of planting to reach maturity and produce fruit. During the winter months the temperature is never very low. Rarely a temperature below 50° F. is recorded; but almost invariably the intensity of the yellowing becomes greater during the months from December to March. The development of this color usually begins to be indicated by a general fading of the green near the margin of the leaves, which rapidly spreads over the entire plant and is followed by a more or less complete blanching of the leaves. Sometimes the yellowing begins as local spots, but these soon spread until the entire plant presents a yellowish-white appearance. This is followed by a cessation of growth; the plant begins to die back from the tips of the leaves; dark brown spots, gradually becoming darker, develop on the leaves, until finally the entire plant dies. Frequently no fruit is produced at all, but that which is formed has a characteristic appearance. The fruit of normal pineapples is deep green in color up to the time of the beginning of the ripening process. Those on manganese soils, on the contrary, are reddish-pink in color throughout the early stages of development and frequently do not contain a trace of green color. On the more highly manganiferous soils the fruit never reaches normal size, and it is difficult to know, by superficial examination, when that which is produced comes to maturity, owing to the similarity in the color between the ripe and unripe fruit.

The interior of the fruit from manganese soil is characterized by a whitish appearance, and usually contains an excess of acidity. Normal pineapples, of the variety grown in Hawaii, are straw colored throughout when thoroughly ripe and golden-yellow on the surface.

The roots of pineapples affected by manganese also present peculiarities worthy of note. Normally the root system is composed of numerous rootlets which branch and subdivide from the larger roots, thus forming a fine network which extends in every direction from the plant to a distance of one or more feet, depending largely upon the physical character of the soil. The root system developed in manganese soil, on the contrary, is much less extensive and contains few rootlets. An examination shows that a large percentage of the roots die some months after formation, although a few live, active roots are usually to be observed, and these are provided with a superabundance of root hairs; in fact, almost every epidermal cell is elongated into a root hair. Such roots are further characterized by a blunt growing tip, which in many instances becomes half as large as a lead pencil, and is frequently swollen into a fleshy enlarged end. The formation of these enlargements appears to mark the end of the growth of the root and death soon follows.

GRAMINEÆ.

Other plants are noticeably affected by manganese, although so far as is known, pineapples are most sensitive to this element. Corn exhibits certain peculiarities. The lower leaves frequently turn brown, die back from the tips, and fall away, and a reddish purple color, sometimes noticed on the stalk and leaf sheath of this plant, forms a pronounced characteristic when grown on highly manganiferous soil. Frequently the purple color extends from the base of the plant to the tassel. The macroscopic examination of the roots reveals no striking variations, except a tendency toward the development of a more pronounced woodiness in the cortex. Without the use of any fertilizing substances, the growth of corn is frequently very scant, the stalk usually small and growth very slow; and in its attempt at reproduction, the tassel is formed when not more than 3 feet high. Sometimes small undeveloped ears are formed. With the use of suitable fertilizers, especially such as contain phosphates, however, corn of normal size and fair yields have been obtained, although a slight browning of the lower leaves, and the development of a purple color on the stalk is not thus entirely overcome.

Panicum molle exhibits certain peculiarities; a general tendency to form less chlorophyll and smaller growth, attended by the formation of a more woody stem, are the most pronounced variations from the normal. The root system seems not to be affected.

Saccharin sorghum shows an appearance similar to that of corn, but perhaps of less intensity.

Rice, when grown as a dry-land crop, becomes yellow soon after germination and shows little tendency to stool or tiller, and appears to be stunted. Its roots are likewise less developed than normally.

Wheat and oats develop a brown appearance on the lower leaves, but are otherwise normal, and a fair growth may be obtained.

Sugar cane appears to be less sensitive to manganese than almost any of the cultivated plants, and shows very slight effects of any sort during the warm summer months. During the winter months, on the contrary, young sugar cane sometimes develops an intense yellowish-white appearance on the leaves, but later this is restored to the normal green, and a thrifty, vigorous growth is obtained. From a practical standpoint the effects of manganese on sugar cane can be ignored, but the development of the etiolated appearance at times indicates some physiological disturbance.

Among the natural grasses in Oahu *Paspalum orbiculare* and *Hydropogon aciculatus* are most abundant in the unplowed areas, and the planters have learned to locate the manganiferous soils by differences in the relative percentages of these two grasses. At the first plowing of this plateau it is not infrequent to find a preponderance of the Hydropogon on the manganiferous soils, whereas Paspalum is by far more abundant on the normal soils. From these differences in the natural growth of these grasses, the pineapple growers have learned to foresee the probable effects of this soil on pineapples; and while it can not be relied upon as an absolute criterion, the indications given by it often furnish a safe guide.

LEGUMES.

In general, the Leguminosæ are affected by manganese somewhat as the Gramineæ. Peanuts become brown in the lower leaves, which subsequently die and fall away, and the stem has a tendency to become purple. The roots show a dark brown appearance.

Jack beans (*Canavalia ensiformis*), likewise, become brown on the lower leaves, which occasionally drop off. The lower part of the stem also shows a purplish color and a stunted growth results. Frequently this plant takes on the appearance of nitrogen starvation, such as characterizes the growth of legumes in the absence of nitrogen-gathering bacteria, although root excrescences indicate the presence of the species that normally infests this plant.

Pigeon peas (*Cajanus indicus*) also appear somewhat stunted, the lower leaves having a tendency to become brown and fall off. In a given length of time the growth of pigeon peas on manganese soil is not more than one-half of that on normal soils. The roots are also

more woody and less extensive, but have been found to contain the nitrogen-gathering tubercles in fair abundance.

Cowpeas (*Vigna catjang*) seem to be the most sensitive of all the legumes observed. The lower leaves, one after another, turn brown and fall away. The stems become purple and a yellowish, stunted appearance results. The roots appear normal and the small amount of seed that is formed seems to be normal.

Kidney beans (*Faba vulgaris*) have been observed to behave very much as jack beans. The lower leaves have a tendency to turn brown and fall away, and a general stunted growth results.

A common species of Crotalaria, from a superficial examination, is unaffected by manganese and grows luxuriantly as a weed throughout the cultivated sections of the islands, and so far as can be observed presents no evidences of any effect from the manganese.

MISCELLANEOUS PLANTS.

Certain weeds, as, for instance, the sow thistle and *Waltheria americana*, also show no effects from manganese.

Cotton grows fairly well and while usually somewhat slower in taking a start the development proceeds normally. Likewise sisal (*Agava sisalana*) is without external effects from the manganese and grows normally. Similarly potatoes, cabbage, and turnips are unaffected in their grosser appearance.

It is claimed that the entire plateau was formerly heavily wooded, but the intervention of the axe and the lack of protection against cattle has resulted in the almost complete destruction of timber throughout this section. Guava bushes are to be found scattered over the unplowed portion, but these have been so eaten by cattle and held in check by intermittent droughts that no deduction relative to the effects of manganese can be drawn. Likewise, *Lantana camara* is found in places, but it also affords no indications.

POT CULTURE EXPERIMENTS.

As will be shown in the second part of this paper, the manganese occurs as a surface accumulation in the soil, being usually much more abundant in the first 10 to 12 inches than in deeper lying strata. Some of the plants previously mentioned are rather deep rooted and have a well-developed taproot system, while still others are cultivated in Hawaii by planting in deep furrows, sometimes 15 inches below the surface of the soil. It was suggested, therefore, that possibly the roots of such plants would penetrate below the manganese layer, and might therefore not have their absorbing surfaces entirely in manganiferous soil. Such could not be the case with surface-rooted plants such as pineapples, the cereals, cabbage, turnips, etc.,

but with cotton and sugar cane, the latter of which is planted in deep furrows, this supposition appears to have some foundation. In order to study this point, as well as have a more strict control and afford easy means of observation with various plants, a large number of pot cultures have been made, using a manganiferous soil, which upon analysis was found to contain 9.5 per cent manganese as Mn_3O_4. For purposes of comparison a normal soil from the grounds of the experiment station, containing 0.2 per cent manganese as Mn_3O_4, was used in a parallel series of pot cultures. The several species of plants were grown in series of three pots of each type of soil. These cultures were made in an open glass house at the experiment station, where close observation was possible, and notes were taken from day to day. The cultures were planted on February 3, and after germination were thinned to a uniform stand of three plants per pot. The following observations on the general appearance and growth of the several species were made and have reference to those in manganiferous soil, except as otherwise noted.

GRAMINEÆ.

After germination normal growth of corn was maintained for about 2½ weeks, after which the leaf sheath around the stalk began to turn purple, the color gradually spreading to the leaves. The lower leaves turned yellow and died back from the tips and one after another dried up and ceased to function, and a very small stalk was formed. The tassel was formed at a height of about 2 feet and no gain was produced. The root development was found to be more extensive than in the normal soil.

No effects from the manganese were observed in the general appearance of wheat other than a slight retardation in the growth.

Oats germinated well and grew to a height of about 6 inches, after which a general retardation in the growth was noticed on the manganese soil, followed later by the development of a pinkish-purple color on the lower part of the stalk. Later on the stunting effect previously noticed seemed to give way to a more normal growth, the usual color and appearance being restored, and the heading time and maturity were practically the same as on the normal soil.

Barley, after reaching a height of 6 inches, stood without making any growth for several weeks; the tips of the leaves turned yellow and gradually died back. Later a partial recovery was noticeable with the development of the normal green color. At maturity the growth was practically the same as on the normal soil.

Paspalum orbiculare made fair growth and showed no effects from manganese further than the development of a purple color on the lower leaves, which seemed to be most pronounced following a period of damp cold weather.

Rice, when cultivated as a submerged crop, turned yellow on the manganese soil and made practically no growth. Repeated trials were made and very little growth was obtained in any instance. The seedlings usually died in 10 days to 2 weeks from the time of transplanting. In the normal soil good growth was secured.

LEGUMES.

Kidney beans developed normally during the first 6 weeks, after which a slight yellowing took place, although vigorous growth was obtained. At harvest time the roots were observed to contain no bacterial tubercles, whereas those from the check soils were well supplied with them. The roots were also found to be brownish in color.

Cowpeas, after germination, turned yellow, and subsequently became very unhealthy in appearance. The lower leaves turned brown and dropped off. The plants remained throughout their growth about one-half the size of those on the normal soil. At harvest time they were found to be fairly well supplied with nitrogen-gathering nodules.

MISCELLANEOUS PLANTS.

Radishes grew normally in each type of soil and showed no visible effects.

Cotton, after reaching a height of 4 or 5 inches, turned slightly yellow, followed by a browning of the lower leaves, especially on the margins, and a general unhealthy appearance resulted.

Mango and avocado seedlings were transplanted to manganese soil in pots and were found to grow normally, and presented no peculiarities.

Tobacco seeds were planted in pots and after germination and the development of four leaves, the plants in the manganese soils ceased to grow for some weeks. Later these plants made considerable growth and became fairly normal, the only noticeable difference at maturity being an apparent thickening of the leaves.

Sugar cane developed a slight yellow color on the lower leaves, but was otherwise normal.

Onions grown from seeds made normal growth during the first 6 weeks, after which the tips of the leaves turned yellow and growth ceased. A very slight bulb formation resulted in the manganese soil, whereas normal bulbs were produced in the checks.

From these observations on the growth of various plants on manganiferous soil, practically the same conclusions may be drawn as in the instances previously noted. A study of the gross characters of these plants seems to justify three conclusions: (1) Some plants may

be injuriously affected by manganese; (2) other species are checked in growth but present no further evidence of physiological disturbance; and (3) still other species are apparently unaffected by manganese. It should be noted that in none of the species mentioned, and so far as the author's observations extend in no species of plant, was any tendency toward stimulated growth on these soils manifested. It should be stated, however, that the ordinary soils of the islands on which comparative observations have been made, contain in every instance at least a small amount of manganese, and as will be shown subsequently, it is usually in a comparatively soluble form, and therefore doubtless exercises some influence on growth. Hence it is not justifiable to conclude from these observations that the small amount of manganese in natural soils is without any significance in plant growth.

PHYSIOLOGICAL EFFECTS OF MANGANESE.

It will be noted that among the plants that show the most pronounced effects from manganese are pineapples, rice, cowpeas, peanuts, kidney beans, pigeon peas, corn, broom corn, and sorghum. With each of these species, and also to a slight extent with certain others, the development of a peculiar color was noticed. A microscopic examination has shown that in each instance this is due to an accumulation in the epidermal cells of colored sap which varies from pink, through various shades, to a deep purple. The brown discoloration previously noted will be subsequently shown to be due to other causes.

With pineapples, however, we are dealing in the main with an utterly different phenomenon, and on account of the economic importance of this crop, together with the fact that it affords examples of the toxic effects of manganese which are to be observed at all times of the year, a detailed study of the chemistry, physiology, and anatomy of this plant has been made. It was thought that on account of the extreme sensitiveness of the pineapple, a careful study of the effects of manganese on it might give a clue as to the effects produced in other plants, still observed in slightly different manifestations and in less intensity. In this investigation a microchemical study of the entire pineapple plant and its several stages of growth, from soils containing varying amounts of manganese, has been made.

MICROSCOPIC STUDIES.

EFFECTS ON THE PROTOPLASM.

The microscopic examination of the several parts of various species of plants has revealed the fact that there is an apparent alteration in the protoplasmic contents of the cells throughout the plant, although the change can not be detected in every cell and it varies in intensity

in the different organs of a given plant. Beginning with the roots, the outer three or four rows of cells, in the case of the pineapple, have a tendency to develop a yellowish-brown appearance in the cell walls. When the plant is grown on a manganese soil, the number of rows of cells thus affected is considerably increased, and sometimes small bodies, dark brown in color, are deposited on the cell walls. These bodies are insoluble in hydrochloric acid of various strengths.

The roots of potatoes also showed a slight brown appearance in the central woody tissue. Likewise, the roots of avocados show a dark-brown ring around the cortex when grown on manganese soil. The appearance of the mango roots, however, is even more pronounced. A dark-brown discoloration in the cell walls and throughout the cell contents is shown in a cross section of these roots; the cell contents are less abundant and the root hairs are light brown in color throughout. The roots of the strawberry show a similar dark appearance in the central canal, the cell walls of which contain dark brown or black incrustations, perhaps MnO_2, as in this instance, they were completely soluble in a 1 to 4 solution of hydrochloric acid. The roots of various other plants were found to contain a somewhat larger percentage of cells with specially thickened tissue adjacent to the cell wall when grown on manganiferous soil. The enlarged tips of pineapple roots, previously referred to, are primarily made up of cells containing this abnormal thickening, and the root hairs are usually shorter.

The growing tips of plants in general begin to die back as one of the first evidences of toxic effect, and this is usually accompanied by a browning of the cell walls and darkening of the cell contents. The pineapple leaf shows an irregular surface when grown under the influence of excessive manganese, giving it the appearance of containing small prominences. A microscopic examination has shown this to be due to a shrinkage in the tissue, which is brought about by the loss of water. These prominences, however, often become dark brown, with a browning of the cell walls, and in some instances there is a disintegration and partial decomposition of the protoplasm itself. Later these spots become larger, until in some instances, the normally liquid contents of the palisade cells become coagulated into a formless mass, which draws away from the cell walls. The protoplasm in the cells which normally bear chlorophyll also breaks away from the cell wall in places, contracting into irregular-shaped bodies. Plasmolysis, therefore, takes place and in a few instances the nuclei have been observed to be brown.

EFFECT ON CHLOROPHYLL.

The first appearance of the effects of manganese is shown in the fading of the chlorophyll, which may be observed in the field in every degree of development from the normal deep green on the one ex-

treme, to yellowish-white plants containing scarcely a trace of chlorophyll on the other. Microscopic examinations show that the fading and ultimate disappearance of the green color is attended by a decomposition and finally the complete disintegration of the chlorophyll bodies. Cross sections of the etiolated leaves show that at first there is a fading of the green color, a change in the intensity of the green color of the chlorophyll granules, without their utter disintegration, but that in successive stages the entire protoplasmic bodies in the cells and all organized arrangement of the protoplasm are broken up. The protoplasm draws away from the cell walls in places and completely loses its organized structure, and in advanced stages there is no trace of a granular structure, such as characterizes normal chloroplastids.

The chloroplastids in the higher plants ordinarily contain two pigments, a green, true chlorophyll, and a yellow, xanthophyll, both of which are soluble in alcohol. After extracting pineapple leaves with alcohol the colorless plastids remaining were found to be somewhat smaller in the plants from manganiferous soil. Upon separating the pigments in the alcoholic extract by means of ether or benzin, it was noted that the chlorotic plants contained very small amounts of the green pigment as compared with the normal, while the occurrence of xanthophyll was about the same in the two instances.

From these facts it seems justifiable to conclude that the etiolation of pineapples is caused by some fundamental change in the protoplasm, which change, however, is not concerned with the yellow pigment, and which does not result in the formation of an increased amount of xanthophyll in the plant. Pineapples in common with other members of the Bromeliaceæ are characterized by a number of rows of palisade cells immediately beneath the epidermis, which cells contain no chlorophyll or only traces of it. In the etiolated plants sometimes these cells seem to be given over to the storage of calcium oxalate; and throughout the entire plant from the tips of the roots through the stalk and fruit into the crown the occurrence of oxalate of lime crystals is greatly in excess of that in normal plants.

EFFECT ON STARCH.

The disappearance of chlorophyll naturally suggested an interference with the formation of carbohydrates, and from a microchemical examination the suspicion is well borne out. The chlorophyll granules, in normal pineapple leaves, are shown by the iodin tests to contain starch in considerable quantities, and frequently the entire granule becomes intensely blue. Near the base of the leaf, starch is stored in considerable quantities, while the stalk is given over very

largely as a repository for this reserve source of energy.[1] Chlorotic leaves, on the contrary, contain very limited amounts of starch, the amount present being in direct proportion to the amount of chlorophyll. In the more advanced stages of chlorosis no trace of starch was detected in the parts of the leaves which normally contain chlorophyll. Near the base of such leaves and in the stalk and roots, however, starch, stored up before the decomposition of the chlorophyll, occurs in abundance, and it is perhaps from this reserve store that the plant very largely derives the energy by which it continues its feeble hold on life.

Pineapples show the most marked effects in starch formation brought about by the toxic effects of manganese; but other species of plants are also affected in this particular. The stems of barley and jack beans were found to contain starch in diminished quantities when grown on manganese soil. As previously pointed out, the growth of onions was particularly affected by manganese, and a microscopic examination of sections of the leaves of this plant failed to show the presence of a trace of starch, whereas it is found in appreciable quantities in the normal plant.

OXIDIZING ENZYMS.

The discovery, by Bertrand, of the presence of manganese in oxidases, suggested to Loew and his associates in Japan the possibility of an increased oxidase and peroxidase activity in plants grown under the influence of manganese compounds, and they have reported the presence of more active oxidizing enzyms in such plants.

As before stated, some plants are much more sensitive to manganese than others; and in some of the lower forms of plant life, especially the fungi,[2] manganese appears to be incapable of bringing about stimulation. These effects suggest that the function performed by manganese is different in different species of plants. Loew [3] pointed out that tobacco showed no increase in the activity of its oxidizing enzyms after having been watered with a dilute solution of manganous sulphate. It has been previously pointed out by the writer [4] that sometimes the etiolated pineapple leaves from manganese soil contain a more active oxidizing enzym than green leaves from normal plants.

A more extensive investigation of this question, however, has shown that the phenomenon previously observed is by no means of universal occurrence. The activity of oxidases and peroxidases in etiolated pineapple leaves is sometimes greater, and sometimes less, than in

[1] For a more complete discussion of the pineapple plant see a forthcoming bulletin of the station.

[2] Molisch, Sitzber. K. Akad. Wiss. [Vienna], Math. Naturw. Cl., 103 (1894), I, p. 554.

[3] U. S. Dept. Agr. Rpt. 65, 1900, p. 22.

[4] Loc. cit.

normal leaves; and while an increased activity sometimes occurs in the etiolated leaves, the total oxidizing power of such extracts is not greater than that of similar ones obtained from normal leaves. Upon standing for a period of 10 minutes, the total oxidation, as measured by the intensity of the color produced in alcoholic solutions of guaiacum or aloin, was equally great with the extract from plants from the two types of soil. These tests have been applied to all parts of the pineapple plants from soils containing manganese varying from 0.1 per cent to 9.75 per cent, and with plants at every age and in the various stages in the development of the chlorosis; and when thus applied to a large series of samples, no correlation could be made between the development of chlorosis, on the one hand and the activity of oxidizing enzyms on the other. Of the many samples tested, oxidases, in limited amounts, and peroxidases, in still greater amounts, occur; but no relation was found between the activity of the enzyms and the appearance of the yellow color. Frequently the normal plants contain a more active oxidase than do the chlorotic plants.

These tests have been extended to various other plants. The leaves of corn grown on manganese soil gave a strong peroxidase reaction, while only a slight reaction was obtained from such leaves when grown on normal soils. *Paspalum orbiculare* grown on manganese soil gave no reaction for oxidase or peroxidase, while a slight bluing of the guaiacum was brought about by the extract of this plant from normal soil. The intensity of the reaction was about equal in extracts from sugar-cane leaves from both classes of soil. Leaves of Crotalaria from manganese soil gave a strong peroxidase reaction, while a less intensive reaction was obtained from leaves when grown on normal soil. Leaves of the olive tree showed the presence of a more active peroxidase when grown on manganese soil. The leaves of oats showed a strong peroxidase reaction when grown on manganese soil and a weak reaction when grown on normal soil. The leaves of cotton, likewise, showed an increased activity in oxidizing enzyms when grown on manganese soil, the total oxidizing power in this instance, however, was not greater. Upon standing for 10 minutes the intensity of the bluing was about equal for plants from both types of soil. Rice showed a similar effect.

The activity of the oxidizing enzyms in specimens of a given species of plant is by no means uniform when grown on normal soils. It has been found, for instance, that extracts obtained from the fresh leaves of normal sugar cane and pineapples, respectively, varied in their oxygen-carrying power between wide extremes; sometimes the leaves of each of these species were found to give a very weak peroxidase reaction, while in other cases the intensity of the reaction was very striking.

It has been shown that pathological disturbances caused by attacks of aphidæ, the mosaic disease of tobacco, etc., are also associated with accelerated auto-oxidation. The autumnal yellowing of plants incident to maturity and the development of yellow spots on certain plants has been shown by Woods[1] to be associated with an increased activity of the oxidases and peroxidases of these plants. This suggested to Loew et al. that the yellowing of plants under the influence of excessive amounts of manganese may be due to excessive auto-oxidation. These authors did not show, however, that etiolated plants grown under the influence of excessive amounts of manganese contain more active oxidase and peroxidase than the same species of plant when grown under the maximum stimulating effects of manganese.

It seems reasonable to suppose, therefore, that while manganese has the power of increasing the oxygen-carrying power of oxidases and peroxidases, and consequently may, in this way, to some degree bring about plant stimulation, the phenomenon of chlorosis can not be completely explained on the basis of excessive auto-oxidation. The development of chlorosis under the influence of manganese is very probably the result of physiological disturbances of a more deep-seated nature.

EFFECTS OF MANGANESE ON THE ANATOMY OF PLANTS.

The microscopic anatomy of certain plants is modified to some extent by the presence of excessive manganese in the soil. As previously stated, the chloroplasts of pineapples became bleached and ultimately decomposed. The effects of manganese are very gradual, and are best observed in the extreme cases. At first there is a gradual fading of the green pigment and a simultaneous reduction in the size of the chloroplasts. These gradually become smaller and smaller until the spongy parenchymatous cells contain only small, slightly yellow bodies where formerly the chloroplasts were abundant.

With the disappearance of the green coloring matter, the absorption of carbon dioxid ceases, and therefore carbohydrate formation comes to an end. This is clearly shown from the absence of starch grains in the leaves. Ordinary green pineapple leaves contain considerable starch, while in the etiolated leaves scarcely a trace of starch occurs. Throughout the etiolated pineapple leaves there are to be found angular bodies similar in appearance to aleurone grains, but which appear to have resulted from an alteration of protoplasm. These occur adjacent to the cell walls, and are most abundant in the cells which show the most pronounced evidences of plasmolysis.

[1] Loc. cit.

The cells in various parts of the plant are also somewhat reduced in size when grown on manganiferous soil, and the cell walls of certain portions of the roots become thickened and fleshy.

The gross anatomy of various species is affected by manganese. As previously stated, corn, cowpeas, pigeon peas, onions, etc., do not attain their normal size on manganese soil. Rice did not tiller as usual. Regarding the effects on root development, mention has been made of the modification in the roots of the pineapple. Certain other plants, as for instance barley, wheat, oats, and jack beans were found to develop an unusual number of fine rootlets. In the case of barley this was especially noticeable. In certain other species, corn in particular, there is a pronounced tendency to form woody roots. The root hairs of the mango were also found to be brown.

COMPOSITION OF THE ASH.

In addition to the effects already mentioned, in studying the function of a given substance in plant nutrition, it is essential to know something regarding its effect on the mineral constituents of plants, and in order to throw some light on this point a large number of ash analyses have been made. If manganese performs a physiological function in connection with the oxidases, or otherwise, it is probable that the composition of the ash will give some indication of this action. For these determinations various plants grown on normal and manganiferous soils were submitted to the usual ash analysis.

Special precautions were taken in selecting the materials for analysis so as to secure representative plants of the same age and stage of development in a given species. In this instance the optional method of the Association of Official Agricultural Chemists,[1] for the preparation of ash from plants was used, and the several determinations were made from samples of the ash thus obtained.[2] Where it was necessary, the samples were leached with distilled water, which was subsequently evaporated to dryness and added to the incinerated residue in making up the ash sample. The table following will show the results.

[1] U. S. Dept. Agr., Bur. Chem. Bul. 107 (rev.), 1908, p. 238.

[2] The plants used for comparison were taken from soils containing various amounts of lime and magnesia.

Ash analyses of plants grown on normal and manganiferous soils.

Plants analyzed.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron (Fe_2O_3).	Manganese (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Soda (Na_2O).	Sulphur trioxid (SO_3).	Chlorin (Cl).	Total ash.
Pineapple leaves 5 months old:	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*	*P ct.*
Manganiferous soil	9.37	2.12	0.81	2.41	9.01	5.70	2.81	21.09	19.48	2.62	13.37	9.94
Normal soil	8.49	1.20	1.11	1.70	7.14	7.60	3.57	22.97	16.72	2.72	13.33	7.14
Pineapple leaves 18 months old:												
Manganiferous soil	5.72	1.76	.96	2.08	15.66	7.91	1.66	14.35	18.86	2.70	13.91	7.98
Normal soil	7.36	.40	.48	1.40	7.00	6.98	2.70	17.12	22.86	3.58	8.86	6.24
Pineapple stalk 5 months old:												
Manganiferous soil	5.20	.40	.60	.25	36.42	2.60	6.12	16.79	2.65	20.99	6.31	8.85
Normal soil	2.27	1.56	.70	.25	23.87	5.82	8.86	24.18	1.65	16.36	9.36	5.12
Pineapple stalk 2 years old:												
Manganiferous soil	1.72	4.52	T.	.80	14.36	7.75	6.70	32.26	1.10	16.81	11.13	7.78
Normal soil	2.84	6.02	T.	.20	12.96	5.78	8.36	33.11	.50	22.93	8.01	6.60
Corn stover:												
Manganiferous soil	25.55	2.63	2.80	.40	8.60	7.64	5.17	22.67	6.67	5.61	5.05	7.55
Normal soil	39.65	1.02	3.20	.15	3.45	4.60	7.56	25.01	1.95	3.48	4.11	9.18
Cowpea vines:												
Manganiferous soil	10.45	1.75	1.60	3.07	22.72	6.93	2.90	21.63	8.70	7.48	3.12	13.73
Normal soil	22.20	7.37	1.90	.87	17.10	9.13	5.03	23.24	8.04	3.52	5.95	13.44
Cowpeas:												
Manganiferous soil	2.64	5.52		.15	1.47	4.15	15.89	....	....	....	....	3.93
Normal soil	2.26	5.43		.00	1.13	6.91	22.71	....	....	....	....	3.53
Paspalum orbiculare:												
Manganiferous soil	66.75	5.21	3.60	2.20	5.30	3.46	2.54	6.04	1.98	4.45	.29	7.88
Normal soil	49.30	6.11	14.00	1.05	6.70	5.05	2.34	4.49	1.87	4.83	.88	7.16
Guava leaves:												
Manganiferous soil	12.00	11.23	3.20	.82	43.02	3.73	4.47	6.15	2.19	9.24	2.31	7.66
Normal soil	11.10	4.52	.48	.28	22.98	10.46	7.70	21.61	2.44	9.73	2.86	6.73
Guava wood:												
Manganiferous soil	4.42	.00	1.28	1.20	52.10	1.51	4.33	10.77	3.82	6.06	.42	5.87
Normal soil	2.05	8.68	.50	.15	26.17	7.22	6.97	28.43	5.28	11.48	1.77	4.02
Sugar-cane leaves:												
Manganiferous soil	39.50	1.62	1.73	.45	14.33	4.41	3.21	17.71	1.38	5.88	3.54	5.57
Normal soil	29.50	.57	2.40	.60	16.60	6.07	4.03	25.10	2.54	6.35	5.67	4.85
Crotalaria:												
Manganiferous soil	16.42	2.90	1.90	1.40	30.80	7.79	4.12	16.27	3.47	8.41	6.85	6.77
Normal soil	13.37	3.60	.80	.05	19.00	21.05	9.13	13.03	4.39	5.96	6.58	6.28
Peanut leaves:												
Manganiferous soil	3.29	2.00	1.30	.25	35.24	5.61	4.49	21.11	.00	3.29	3.54	10.45
Normal soil	5.65	.76	2.41	.04	39.41	10.99	4.97	12.39	.82	2.49	2.20	9.95
Peanut stems:												
Manganiferous soil	7.64	12.00	3.88	2.56	14.80	9.04	2.00	26.57	2.82	4.84	3.54	11.15
Normal soil	4.90	3.13	2.06	.32	21.76	19.02	4.81	26.11	2.92	5.54	1.42	7.12
Ironwood (*Casuarina equisetifolia*) needles:												
Manganiferous soil	3.68	5.62		.66	37.50	4.57	1.62	....	....	....	6.95	....
Normal soil	.86	5.29		T.	43.12	7.75	4.23	....	....	....	7.87	....
Olive leaves:												
Manganiferous soil	9.12	7.99	5.60	.64	26.32	1.84	2.63	20.52	5.85	4.34	1.27	....
Normal soil	15.18	9.70	8.88	.86	17.80	1.53	2.78	17.02	5.79	5.17	1.99	....
Waltheria americana leaves:												
Manganiferous soil	9.80	7.31	3.84	8.70	31.30	3.81	2.80	11.16	.30	3.32	3.43	....
Normal soil	6.82	7.89	3.20	.82	29.62	5.44	3.81	16.37	.81	4.43	4.49	....
Waltheria americana stems:												
Manganiferous soil	2.23	8.40		.56	14.97	11.70	3.67	....	....	....	....	3.58
Normal soil	2.49	5.96		.45	13.70	11.30	3.46	....	....	....	....	3.73
Broom-corn leaves:												
Manganiferous soil	29.52	4.77	2.37	2.24	12.08	6.75	.94	20.84	3.98	2.88	5.91	....
Normal soil	62.40	5.30	2.92	.60	5.44	3.52	1.38	8.96	2.82	1.39	2.62	....
Broom-corn stalks:												
Manganiferous soil	9.60	5.67	3.39	1.36	2.12	3.12	1.02	....	....	6.57	8.01	....
Normal soil	34.20	4.84	4.12	.52	1.88	2.51	3.72	18.49	11.80	6.44	4.68	....
Tobacco stems:												
Manganiferous soil	3.17	4.26		.57	9.47	4.08	2.08	....	....	....	....	7.02
Normal soil	5.17	10.05		T.	1.88	3.27	7.35	....	....	....	....	8.50
Pigeon-pea leaves:												
Manganiferous soil	25.94	23.90		1.43	16.11	3.25	4.04	....	....	....	....	12.17
Normal soil	16.53	26.84		.15	7.86	7.66	10.85	....	....	....	....	7.84
Pigeon-pea stems:												
Manganiferous soil	4.65	5.46		.99	15.29	2.82	4.25	....	....	....	....	5.81
Normal soil	3.34	16.85		T.	3.79	4.39	9.34	....	....	....	....	6.22
Oat straw:												
Manganiferous soil	22.15	3.82		.86	9.15	5.16	.73	....	....	....	....	10.27
Normal soil	33.29	7.97		T.	3.40	3.19	8.81	....	....	....	....	11.73
Wheat straw:												
Manganiferous soil	29.72	2.90		.22	4.51	4.03	2.96	....	....	....	....	8.91
Normal soil	63.81	1.98		T.	2.09	2.74	5.56	....	....	....	....	16.27
Mango leaves:												
Manganiferous soil	29.25	4.27		2.16	33.12	2.15	2.89	....	....	....	....	9.24
Normal soil	43.66	4.51		.24	17.13	4.90	5.43	....	....	....	....	8.21

These data show some striking variations in the composition of the ash. Irregular fluctuations in several elements are to be noted. It is well known, however, that a given species of plant, when grown under different conditions, such as different types of soil and climatic variations, give ashes of different compositions. *In practically every instance the absorption of manganese was increased on the manganese soil.* The variations in the composition of the several species above given show that there is a pronounced difference in the percentages of lime, magnesia, and phosphoric acid in the ash of plants from the two classes of soils.

Almost universally with the plants examined, the percentage of lime, both when calculated to a basis of the ash or in terms of the dry weight, was found to be in great excess in the plants from manganese soil over that in normal plants. As regards magnesia, there is a pronounced tendency toward the absorption of a diminished quantity from the manganese soils, while the phosphoric acid is almost uniformly absorbed in considerably smaller quantities per unit of dry matter, or as expressed in percentages of the ash. The plants analyzed showed a wide range of effects from manganese, as judged by their gross appearance. Some are not visibly affected, others little so, while still others show a pronounced toxic effect. Uniformly throughout the tendency toward an increased absorption of lime, on the one hand, and a decreased absorption of phosphoric acid and magnesia on the other, is noted.

It has been shown by Loew and others that various plants are affected differently by different ratios of lime and magnesia; certain species of plants will vegetate most advantageously when the ratio of lime to magnesia is as 1 to 1; whereas still other species thrive best when the ratio is as 1 to 3, etc. In the publications dealing with this subject, however, mention is usually made of the effects produced upon the appearance of the plants, and it is to be regretted that so few ash analyses have been made in this connection. From the data obtainable, however, it appears that where the physiological balance between lime and magnesia is disturbed, a corresponding influence is brought about in the composition of the ash.

Under the influence of manganese plants automatically modify themselves in regard to the absorption of these two elements, and as is well known, it is not so much the absolute amount of calcium and magnesium in a given soil as the ratio between these two substances that determines the physiological effects.[1] In order to bring out the relationship more clearly, the relative amounts of calcium and magnesium absorbed from normal and manganiferous soils, respec-

[1] As shown by a number of recent investigations, magnesium appears to be a normal constituent of chlorophyll. This fact may be associated with the development of chlorosis in the pineapple when grown under the influence of excessive manganese.

tively, have been recalculated from the previous ash analyses and are presented in the following table:

The ratio of lime to magnesia in plants (magnesia considered as 1).

Kind of plant.	From manganiferous soil.	From normal soil.	Kind of plant.	From manganiferous soil.	From normal soil.
Pineapple leaves:			Ironwood needles	8.20	5.56
5 months old	1.58	.94	Olive leaves	14.30	11.63
18 months old	1.98	1.00	*Waltheria americana:*		
Pineapple stalk:			Leaves	8.21	5.44
5 months old	14.00	4.10	Stems	1.28	1.21
18 months old	1.88	2.24	Broom corn:		
Corn stover	1.12	.75	Leaves	1.79	1.54
Cow peas:			Stems	.67	.74
Vines	3.28	1.86	Tobacco stems	2.32	.57
Seed	.35	.16	Pigeon peas:		
Paspalum orbiculare	1.53	1.32	Leaves	4.69	1.02
Guava:			Stems	5.42	.86
Leaves	11.53	2.19	Oat straw	1.79	1.07
Stems	34.50	3.62	Wheat straw	1.12	.76
Sugar cane, leaves	3.25	2.73	Mango leaves	15.40	3.49
Crotalaria	3.95	.90			
Peanut:					
Leaves	6.28	3.58			
Stems	1.63	1.14			

An inspection of these data shows that in almost every instance the ratio of the absorbed lime to absorbed magnesia is increased under the influence of manganese.

THE DISTRIBUTION OF MANGANESE IN PLANT ORGANS.

Regarding the deposition of manganese in the various plant organs, authorities are not agreed. Certain investigators have observed it to be present in greatest abundance in the leaves and active growing parts of plants, while still others have found it to be deposited at maturity in the grain. Occasionally it has been reported as in part assuming a concretionary form and being deposited in the cell walls or on the surface of leaves, etc., and finally in some species it is stated to be present in the cell sap only.

The investigations already recorded show that the deposition in various species is not always the same. In certain plants which contain strongly acid sap, as for instance the pineapple, the manganese appears to be in solution in the cell sap. Pineapple leaves were macerated and leached with distilled water, by means of which it was found that practically the entire manganese content was leached out. In addition, no evidence of a deposition of any manganese compound in pineapples was observed in the microscopic studies herein reported.

In certain other plants, strawberries and mangoes in particular, manganese is deposited on the cell walls. In regard to the distribution of manganese in the various parts of plants, the following determinations will be of some interest:

Percentage of manganese in the ash from various parts.

Kind of plant.	Mn_3O_4.	Kind of plant.	Mn_3O_4.
	Per cent.		*Per cent.*
Pineapple:		Corn:	
Leaves	2.08	Leaves	0.66
Stalk	.20	Grain	.00
Fruit	Trace.	Peanuts:	
Guava:		Leaves	.25
Leaves	.82	Stems	2.56
Stems	1.20	Crotalaria:	
Waltheria americana:		Leaves	3.12
Leaves	8.70	Stems	1.48
Stems	.56	Seeds	.80
Broom corn:		Cowpeas:	
Leaves	2.24	Leaves and stems	3.07
Stems	1.36	Seed	.15
Sorghum:		Pigeon peas:	
Leaves	.89	Leaves	1.43
Stems	.79	Stems	.99
Wheat:			
Leaves	1.40		
Stems	1.40		
Grain	.68		

From these data it is apparent that the distribution of manganese in the different parts of plants varies in different species, but is usually greatest in the leaves. In no instance was it found in greatest concentration in the seed.

CONCLUSIONS.

From the preceding investigation it has been shown that various plants when grown on manganiferous soil are affected differently. Some species are stunted in growth and die back from the tips of the leaves, which turn yellow or brown and frequently fall off, and a general unhealthy appearance results. Other species appear to be unaffected and so far as can be judged vegetate normally in the presence of manganese. Microscopic investigations have shown that in certain instances the protoplasm undergoes changes. Occasionally it draws away from the cell walls, the nuclei become brown, and plasmolysis takes place.

The chlorophyll in a number of plants is affected. In pineapples it undergoes decomposition, the chloroplasts often becoming completely disintegrated and losing their usual granular structure. Simultaneously with the destruction of chlorophyll starch formation ceases.

The occurrence of oxidizing enzyms in plants appears to bear no relation to the destruction of chlorophyll under the influence of excessive manganese. While the oxidases generally contain manganese as a normal constituent, or at least manganese is closely associated with the oxidases and at the same time their oxygen-carrying power is accelerated by the presence of manganese salts, the foregoing investigations show that there is no correlation between the phenomenon of chlorosis in pineapples and the activity of the

oxidizing enzyms. The decomposition of the chlorophyll in this case therefore is not due to excessive auto-oxidation. This does not imply, however, that accelerated auto-oxidation in plants is without effect.

From the ash analyses it was found that manganese was absorbed in considerable quantities, and in nearly every instance was greater in the plants from manganiferous soil. The ash analysis also shows that a disturbance of the mineral balance takes place. The percentage of lime is increased, while the absorption of magnesia and phosphoric acid is decreased. Some of the plants analyzed showed a marked toxic effect due to manganese, while others appeared to be unaffected; but in practically every instance a modification of the mineral balance was observed, and this was found to follow the same direction in all species. The ratio of absorbed lime to absorbed magnesia increased under the influence of manganese, regardless of whether the plant showed a toxic effect.

From these evidences we may believe that the effects of manganese are largely indirect, and are to be explained on the basis of its bringing about a modification in the osmotic absorption of lime and magnesia, and that the toxic effects are chiefly brought about through this modification, rather than as a direct effect of the manganese itself. As has been mentioned already, not all species of plants are equally sensitive to modifications in the lime-magnesia ratio, and likewise different ratios are best suited to different species. Therefore the effect of manganese may be very different in different species of plants. With certain plants it is toxic for the reason that the lime and magnesia are thrown out of their optimum ratio for this plant, while with other plants it may exert a stimulating effect by bringing this ratio more nearly to its optimum for these species.

If we are to accept Loew's theory regarding the function of magnesium in plant growth—namely, that it acts largely as a carrier of phosphoric acid—we may come to a better understanding of the data in this connection. According to theory, magnesium phosphate being more easily hydrolizable than the calcium phosphate, a relatively large amount of magnesium in the cell sap prevents the precipitation of phosphoric acid as calcium phosphate, which would tend to remove it from the cell sap, and consequently throw it out of the field of action. Magnesium, therefore, by virtue of mass action, holds in solution this essential for protoplasmic formation. If an excess of calcium should be introduced into the cell sap, however, as is the tendency with plants which grow on manganiferous soils, there would be a tendency to precipitate the phosphoric acid from solution, and thus to interfere with the formation of protoplasm.

The small amount of manganese in natural soils, therefore, probably performs a twofold function in plant growth: (1) It acts catalytically, increasing the oxidations in the soil and accelerating the auto-oxidations in plants; and (2) it tends to modify the absorption of lime and magnesia, perhaps by partially replacing calcium from insoluble combinations, and, by a direct effect on the osmotic absorption of lime and magnesia, increasing the former and decreasing the latter.

The absorption of phosphoric acid is likewise decreased in the presence of manganese. By reference to the table of ash analyses it will be seen that frequently a given species of plant was found to have absorbed not more than one-half as much phosphoric acid from manganese soil as from normal soil. The interference with the absorption of phosphoric acid would also tend to bring about stunted growth, and might be sufficient to account for the differences in the size of plants from the two classes of soil. A possible explanation of the effects on absorption of phosphoric acid is found in the manganese. By reference to the second part of this paper it will be seen that manganese exists in the soil largely as MnO_2, which is quite soluble in organic acids, giving rise to the proto-salts. Phosphoric acid coming into solution in the soil moisture would tend to be precipitated by the manganese as manganese phosphate, a difficultly soluble compound, and hence in this way the absorption of phosphoric acid by plants might be hindered.

In harmony with these ideas are certain experimental demonstrations. It is a matter of common knowledge among the pineapple growers that the application of lime to manganiferous soils results in the production of a more intense yellowing in a shorter length of time than is produced without it. No surer means of pineapple failure can be adopted on manganiferous soils than the application of lime. On the other hand, it has been shown that the application of soluble phosphates [1] tends to ameliorate the effects of an excess of manganese. In practice this is the only means that is known to be efficacious, but in the case of pineapples it does not prevent the development of the yellow color.

Concerning the form in which manganese is absorbed very little can be said definitely. It has been found that a given compound of manganese acts differently with one and the same crop when applied to different soils. This may be partially explained on the basis of an indirect effect on the other bases of the soil. On the other hand, certain compounds appear to be toxic, while others act as stimulants when used in equal concentrations. Salomone found that the toxicity for wheat and barley was greater with compounds in which the

[1] Cf. Guthrie and Cohen, loc. cit.

element played the rôle of an electronegative element (manganates, etc.). Frequently it has been observed that applications of manganese dioxid produced equally as great or greater effects than a soluble salt, like manganese sulphate or chlorid. Recently, in discussing the peculiarities of pineapples on the manganiferous soils of Oahu, James [1] suggested that the manganese is probably absorbed as a manganite of calcium, of which there are a number.

In the presence of the higher oxids of manganese or their hydroxids soluble calcium compounds would probably form one or more of the calcium manganites, and the fact that the application of lime increases the toxicity of manganese, together with the fact that the absorption of lime by plants is increased in manganiferous soils, gives some support to the view that a calcium manganite is formed.

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[1] Hawaiian Forester and Agr., 8 (1911), No. 6, p. 176.

THE ORIGIN, COMPOSITION, AND PROPERTIES OF THE MANGANIFEROUS SOILS OF OAHU.

INTRODUCTION.

The island of Oahu is made up of two almost parallel mountain ranges, the Koolau on the east and the Waianae on the west, with a sloping plateau of about 10 miles in width and 40 miles in length between these. The entire island is volcanic, with extinct craters in the mountain ranges, and a number of lateral cones on the coastal slopes, particularly near the southeastern point of the island. The central plateau comprises an irregularly rolling plain, which slopes gently from the mountains on the east and west, toward the central and lower portion, from whence a gentle slope extends to sea level on the north and south, respectively.

This plateau comprises the principal portion of the arable land of Oahu, and rises very gradually from sea level to an elevation of about 800 feet in height from north to south, while there is also a general slope from the mountain ranges on either side. In no considerable area of the plain is there a slope of more than a few degrees. Numerous gulches or deep ravines originating in the mountains traverse the plain, thus furnishing natural water courses for the excessive precipitation of the islands, which is most abundant in the Koolau Mountains.

The depth of the disintegrated detritus, of which the soil is a part, varies from 1 to perhaps 20 or more feet in places, and is underlaid by normal basaltic lava of essentially the same structure and composition throughout, and very similar to that which forms the rock-ribbed foundations and strata of the mountain ranges. The composition and characteristics of the soil vary between wide extremes, the larger portion of which is typical laterite, similar to the red, highly ferruginous soils of the entire island group, and closely resembling the soils of other volcanic islands of the Pacific.

From the evidences at hand, the soil and deeper-lying disintegration products have resulted principally from the primary decomposition of normal basalt, under the influence of the usual weathering agencies incident to a humid subtropical climate. In some localities more drastic chemical agencies may have had a part in the early changes set up in the lava soon after ejection. The ever-present

sulphurous vapors around the active volcanoes of Hawaii in recent times may have accompanied the ancient flows that builded up the mountain ranges and plateaus of Oahu, and the sulphuric acid formed from the oxidation of the burning sulphur may at least have taken part in the initial disintegration of the lava; but it is safe to conclude that the main body of disintegrated lava, which is spread out over the entire plain, and a large part of which has been washed down from the greater elevations in the mountains, represent segregation and disintegration products resulting from the operation of normal weathering agencies.

THE LOCATION OF MANGANIFEROUS SOILS.

The natural slope of the plain toward the sea at either end is considerably greatest from the sea level to an elevation of about 650 feet, above which the fall is very gentle. At intervals in this upland plain, and scattered promiscuously from one end of the island to the other over a distance of 15 or more miles, there are areas of various sizes and every shape which are made up of soil quite unlike that surrounding them, and which contain, in many instances, large quantities of manganese. The location of these sporadic manganiferous outliers is usually toward the lower and more central part of the upland portion of the plain, and they are generally found at elevations of from 650 to 900 feet. Sometimes the manganese soil occurs in local areas of not more than an acre in extent, while it is not uncommon to find areas of 20 or more acres in one body; but almost uniformly the manganese soil is located at or near the base of a long, gentle slope, or on a rather level expanse, and sometimes in a shallow basin.

ORIGIN OF THE SOIL.

The occurrence of soils containing such high percentages of manganese, which is, so far as is known, unlike any similar areas elsewhere, naturally calls for some inquiry concerning its origin. More especially is this true when we consider that the entire island group is of volcanic origin and of comparatively recent formation. The lavas throughout the islands belong to the typical basaltic type, and while disintegration and physical segregation of the lava proceeds rapidly under a moist tropical climate, thus rapidly breaking up the lava into a finely divided residuum, true mineralization has not been in progress sufficiently long to affect a very pronounced mineral segregation. Minerals thus understood are a comparative rarity in the islands. In the cooling of the molten magma certain rather definite substances separate into fairly definite mineral forms, such, for instance, as olivine, magnetite, etc., but the disintegration products

that have resulted from simple weathering or a combination of weathering and more radical chemical forces, such as the gases accompanying the eruption and flows, are comparatively few in number and may be said to be simple in composition. Mineralogists, as a rule, therefore, have not taken great interest in the islands.

The basaltic lavas of the islands are classified into several classes, but these classifications are in the main based on physical rather than chemical differences. The absolute chemical composition of the unaltered lavas of the islands, while varying from place to place, does not afford fundamental differences sufficiently distinct to form a basis of classification. The unaltered lava then, for our purposes, may be looked upon as a single rock. Particularly is this true of the rock masses that constitute the mountain ranges of Oahu, and the lava-flows which have given rise to the soils of the plain between the Waianae and Koolau Mountains. No detailed geological investigation of the rock masses and formations in these mountains has been published, but numerous geological observations have been made and specimens from various parts examined sufficiently perhaps to warrant the conclusion above drawn.[1]

CHARACTER OF THE SOIL.

The soil that arises from the disintegration of the lava possesses properties that are very characteristic. In general they may be classified as highly ferruginous and of fine texture. The disintegration usually has been complete. Few pebbles or small stones occur in the soil and subsoil, and practically the entire mass is reduced to an impalpable powder. The principal changes that have taken place between the lava on the one hand and the soil on the other, are those of oxidation and solution. There is, of course, every stage of this change represented in these soils, although the main body of the soil and subsoil of this plain represents almost complete decomposition.

COMPOSITION OF THE LAVA.

The lava contains about 11 per cent iron completely disseminated throughout, and in the unaltered condition this is largely in the ferrous state. It is of a dark gray color and usually quite regular. In weathering the iron becomes oxidized, thus taking on a reddish-brown color, which varies owing to different degrees of hydration or the subsequent reduction, under the influence of decaying organic matter in the partial absence of free oxygen.

[1] C. H. Hitchcock. Geology of Oahu, Bul. Geol. Soc. America, 11 (1900), pp. 15–60. Hawaii and Its Volcanoes. Honolulu, 1909.

The accompanying table shows the composition of normal lavas taken from different parts of the plain, and may be looked upon as fairly typical:

Analyses of lavas from Oahu.

Constituents.	A.	B.	E.	F.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	52.45	52.15	51.98	52.24
Alumina (Al_2O_3)	11.49	12.57	15.85	16.00
Ferric oxid (Fe_2O_3)	3.66	3.36	2.90	3.73
Ferrous oxid (FeO)	6.90	7.07	6.84	5.89
Manganese oxid (Mn_3O_4)	.36	.50	.92	.68
Lime (CaO)	10.32	8.54	9.57	9.54
Magnesia (MgO)	5.81	6.51	5.61	5.90
Potash (K_2O)	.89	.84	.97	.86
Soda (Na_2O)	2.44	2.64	2.70	2.65
Sulphur trioxid (SO_3)	.20	.61	.51	.53
Phosphorus pentoxid (P_2O_5)	.38	.28	.22	.11
Titanic dioxid (TiO_2)	4.07	2.07	1.50	1.50
Combined water (H_2O)	1.02	.94	1.04	.54
Total	99.99	100.08	100.61	100.17

For purposes of comparison, samples of soil immediately adjacent to the lava were also analyzed. The strata are frequently made up of large bowlders of lava, which upon weathering show a concentric structure, being apparently made up of successive layers of lava which possibly accumulated during the slow flow, and in part is perhaps due to the cooling of successive layers proceeding from without toward the center. It here affords a good opportunity for a study of the changes that take place in the successive decomposition and weathering of the lava, for successive layers still showing the structures of the lavas, are to be found in every stage of decomposition from the unoxidized and unaltered rock, on the one hand, to completely oxidized and weathered soil, on the other. Recent cuts made by building roads across the ravines and gulches expose these decomposing bowlders in numerous places, and, in addition, give good opportunity for a study of the general question of stratification and decomposition throughout the plain.

COMPOSITION OF LAVA-ALTERATION PRODUCTS; THE EFFECTS OF LEACHING.

The composition of these weathered products is shown in the following table:

Analyses of lava disintegration products.

Constituents.	C.	D.	G.	H.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	20.29	24.01	26.82	32.00
Alumina (Al_2O_3)	37.97	36.27	30.13	35.28
Ferric oxid (Fe_2O_3)	15.01	14.29	16.86	11.80
Ferrous oxid (FeO)	3.22	3.31	3.03	1.53
Manganese oxid (Mn_3O_4)	.19	.43	.06	.08
Lime (CaO)	.33	.17	.22	.22
Magnesia (MgO)	.20	.09	.11	.14
Potash (K_2O)	.25	.24	.46	.30
Soda (Na_2O)	.27	.31	.57	.61
Sulphur trioxid (SO_3)	.78	.49	.74	.70
Phosphorus pentoxid (P_2O_5)	.23	.34	.19	.04
Titanic dioxid (TiO_2)	4.69	4.82	2.21	2.13
Combined water (H_2O)	16.84	15.61	18.34	15.06
Total	100.27	100.38	99.74	99.89

Sample C was taken from adjacent to lava sample A.
Sample D was taken from adjacent to lava sample B.
Sample G was taken from adjacent to lava sample E.
Sample H was taken from adjacent to lava sample F.

By comparing these analyses with those in the previous table it becomes apparent that great changes take place during this process. The iron becomes oxidized to a large extent; the color consequently changes from a dark gray to a reddish-brown; the calcium, magnesium, sodium, and potassium are very largely leached out as silicates by the heavy rains that frequent the sections, thus giving rise to a soil that contains a large percentage of iron and alumina and correspondingly small amounts of calcium, magnesium, sodium and potassium. Leaching, therefore, plays a greater part in determining the composition of the soil than perhaps any other factor. As further proof of the correctness of this view, Maxwell[1] points out that the waters of the natural streams of the islands contains these elements in large quantities. It is noteworthy in this connection that the percentage of manganese was in every instance found to be less in the soil around these bowlders than in the unaltered lava. It should also be remembered that on account of the great concentration that takes place, due to dissolution of calcium, magnesium, potassium, silicon, etc., those elements not appreciably dissolved would necessarily become concentrated in passing from the lava to the soil; hence, a greater dissolution of manganese than the mere analytical data indicate, must have taken place.

By referring to the analyses of red (and for the present, normal soil (see p. 51), since it represents the usual residuum arising from the

[1] Lavas and Soils of the Hawaiian Islands. Honolulu, 1898, p. 162.

normal weathering of the lava, and is quite similar in composition to the main body of soils throughout the islands), we note a striking similarity between their composition and that of the weathered product collected from around unaltered lava. These red soils constitute the chief arable land of this plain, the manganese areas being localized spots in the general soil.

THE OCCURRENCE OF MANGANIFEROUS SOIL.

The location of manganese soil in the lower parts of the comparatively level portion of the plain and its occasional occurrence in a slight depression suggests solution and segregation as possible factors in the transfer and subsequent deposition of this material. The surface soil throughout the plain is undoubtedly colluvial and alluvial, having been derived from greater elevations; but by no means can the entire mass of disintegrated material, which often extends to a depth of 15 or 20 feet in places, be looked upon as having thus been transferred from the lava of its origin. A sharp line of stratification is shown at many places on the cut edges of the gulches and in excavations made in road building, etc., clearly marking the alluvial layer from that which is sedentary or residual. The alluvium varies in thickness from about 2 to 8 or 10 feet in places, and constitutes the surface soil of the plain.

It is in this alluvium that the manganese uniformly occurs. Nowhere does the decomposed residuum show an accumulation of manganese, neither has a highly manganiferous lava been discovered, although search has been made for such. The manganiferous areas are localized and in no sense continuous, and the percentage of manganese uniformly decreases from the surface downward. Frequently the soil contains 5 per cent manganese, whereas the subsoil at a depth of 30 inches contains less than 1 per cent.

In localities where the alluvium is deepest, highly manganiferous material is found at a depth of 6 to 8 feet. In one location the soil was found to contain 9.7 per cent Mn_3O_4, the entire mass being very finely divided and containing no particles larger than 1 millimeter in diameter; whereas the subsoil at a depth of 36 inches contained 8.50 per cent Mn_3O_4. At this depth, however, the manganese occurred largely in the form of concretions, some of these being ½ inch in diameter. At depths below the alluvial deposit the residuum contains less than 0.5 per cent Mn_3O_4. Within 50 yards from this spot the soil on every side of it, save that of the natural drainage, contains less than 1 per cent of manganese, and successive borings at various depths failed to reveal the presence of more highly manganiferous materials.

Throughout the plain the low-lying areas contain manganiferous concretions of all shapes and sizes, ranging up to a size of ½ to ¾ inch

in diameter. These uniformly show the concentric shell structure of concretions deposited from solution, and are arranged around a nucleus of some sort, usually of red substance similar to the red soil.

LEACHING OF THE MANGANESE.

Heavy precipitation is a pronounced characteristic of the Koolau Mountain climate, the run-off draining through the natural gulches of the districts. Some of these streams are continuous throughout the year. It has been noticed that the bowlders and pebbles in the bed of these small streams are coated over with a black film, which upon examination has proven to be the higher oxids of manganese. In some instances pieces of vesicular lava lying in the bed of a drainage ditch were found to contain numerous manganese concretions imbedded in the surface cavities. No cavity or vesicle which did not have direct open connection with the surface contained manganese concretions. In these instances the manganese was deposited on these stones from solution in the natural drainage water. Some of these incrustations are of quite recent deposition, and without doubt the drainage waters from lavas that are undergoing disintegration at the present time contain manganese in solution, although it is present in very minute quantities.

In this connection it is of interest that the previously published analyses of Hawaiian lavas [1] show the presence of manganese as a general constituent, and in some instances it has been found to be present in the lava to the extent of 1.91 per cent, expressed as MnO. Other samples taken from Kilauea range from a trace to 1.72 per cent. It is safe to say that manganese is a constituent of all normal lavas of the islands.

In the disintegration and weathering of basalt, therefore, manganese becomes soluble and leaches out. The drainage waters necessarily contain this element, which subsequently becomes oxidized and is precipitated around various nuclei, or as a film on the surfaces of stones in the drainage waters. Thus far this discussion has kept close to experimental facts which are being demonstrated on a grand scale wherever lava is undergoing disintegration under semihumid climate in the islands.

THE PROBABILITY OF SUBMERGENCE.

During the cruise of the "Challenger" expedition in 1873–76 [2] it was found that at various places between Hawaii and Japan, to the south of Hawaii and scattered promiscuously over the southern Pacific, the floor of the ocean contained manganese concretions. In

[1] Hitchcock, Hawaiian Forester and Agr., 8 (1911), p. 27.

[2] Report on the Scientific Results of the Voyage of H. M. S. Challenger, 1873–76. Deep Sea Deposits by J. Murray & A. F. Renard. London, 1891, pp. 337–412.

some instances the reports state that the dredge brought up a ton or more of these, which were of varying sizes and shapes, sometimes as large as cricket balls. In some localities these were much more numerous than in others, and they were entirely wanting in still others. Microscopical and chemical analyses showed these concretions to have almost the same composition as the concretions that occur throughout the manganiferous soils of Oahu. For the sake of comparison, analysis of concretions from each of these regions is submitted in the following table:

The composition of manganese concretions.

Constituents.	From Oahu.	From the Pacific.[1]	Constituents.	From Oahu.	From the Pacific.[1]
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Silica (SiO_2)	16.74	13.58	Titanium oxid (TiO_2)	3.26	....
Alumina (Al_2O_3)	25.48	3.53	Lime (CaO)	.20	....
Ferric oxid (Fe_2O_3)	9.00	20.64	Loss on ignition less oxygen	18.75	....
Manganese dioxid (MnO_2)	23.08	28.17			
Manganous oxid (MnO)	2.88	....	Total	99.39	....

[1] Average of 34 samples. See Challenger Report, Deep Sea Deposits, p. 370.

A comparison of these data shows a parallelism in the composition of the concretions from the two localities, especially as regards the percentages of manganese, silica, and iron. It should be stated that the composition of the concretions from the floor of the Pacific as well as those from Oahu varies considerably. Some of the concretions are made up very largely of the higher oxids of manganese with only small amounts of other substances, while in other cases the percentage of manganese is relatively less. The nature of the mixture in a given case seems to be somewhat accidental and dependent upon the condition and occurrence of the various substances associated with the manganese. Some of the concretions from the Pacific contained considerable amounts of lime and magnesia. The unreported balance in the above analyses is largely to be referred to these substances.

The sharp line of demarcation separating the alluvial deposit from the sedimentary indicates that at some time since the laying down of the foundation of the plain by lava flows an inundation has taken place. The evidences do not point to a submergence of great depth, for the alluvium becomes of less thickness in passing from the lower to the higher portions of the plain, while in the mountains there is nowhere any sign of there having been submergence.

In this connection it is of interest to note that Hitchcock,[1] in discussing the formation of Oahu, states that at first Kaala, the highest peak of Oahu, made its appearance above the ocean followed by

[1] Hawaii and Its Volcanoes, p. 21.

Koolau, thus forming two islands, which were later connected by subsequent lava flows. On account of its bearing on this point the words of the author will be quoted:

The Kaala dome existed before the Koolau Mountains were raised very much above sea level. The ocean came, perhaps, half way across the islands, and the trade winds impinged against the basaltic piles, dropping moisture which excavated the eastern side very completely, together with the Waianae Wind Gap. * * * In later times the Koolau came up from the depths and poured over the skeleton ridges on the east side of Kaala so as to conceal them from view and underlaid the plateau with nearly horizontal sheets of basalt.

In addition, the same author points out that in his opinion, based on the occurrence of marine shells in cultivated fields at Waialua, and coraline remains in the crater at Diamond Head, together with such occurrences near Kaimuki and at Kahuku, that Oahu underwent a subsequent depression to the extent of 250 feet.

With the additional observation concerning the occurrence of an alluvial sheet over the principal part of the plateau containing manganese concretions similar in every way to those found on the floor of the Pacific, it is reasonable to suppose that the submergence was greater than formerly believed to have been, and possibly extended over the entire plateau after the time of the lava flows.[1]

If we accept this view, the accumulation of the manganese soils and their origin can be easily explained. The manganese originated from the normal lavas which became dissolved during weathering and disintegration, just as it does at the present time. In solution, probably as carbonate, it was washed down from the mountains, and upon subsequent oxidation was precipitated in the form of concretions, and deposited along with the highly ferruginous sediment which the descending waters must have borne. If originating and transported in this way, the deposition of manganese would naturally be greatest in the low places. In addition the specific gravity of the manganese concretions is less than that of unaltered lava or the ferruginous soil which accompanies it, which would also tend to favor their deposition in the lower altitudes. And probably a final factor in the accumulation of the manganese in the soil is to be found in the solubility of the manganese subsequent to deposition. Further on it will be shown that the manganese is somewhat soluble in water, greatly so in weak organic acids. The heavy rains that frequent the plateau at times naturally leach soluble substances toward the lower levels, where, on account of the greater depths of the detritus, surface drainage is much less than at higher levels. Substances thus dissolved would tend to accumulate in the lowest places, and would naturally become concentrated near the surface through the force of capillary rise of moisture during the long dry seasons, when the upward flow of capillary moisture must be very great.

[1] This idea is in accord with the Tertiary theory of artesian water supply in the islands. See Hitchcock, Hawaiian Forester and Agr., 8 (1911), p. 27.

COMPOSITION AND PROPERTIES OF THE SOIL.

The manganiferous areas are characterized by properties not possessed by the soils surrounding them; they are dark brown or black in color, finely pulverized, and easily tilled; they do not compact by heavy rains, and are naturally well drained. The normal red soils are characterized by extreme heaviness, and have a pronounced tendency to become puddled. Tillage therefore is difficult and the drainage poor.

The accompanying analyses show the composition of these soils:

Composition of manganiferous and normal soils of Oahu.

Constituents.	Manganiferous soils.									
	Soil. No. 9.	Subsoil. No. 10.	Soil. No. 11.	Subsoil. No. 12.	Soil. No. 15.	Subsoil. No. 16.	Soil. No. 27.	Subsoil. No. 28.	Soil. No. 51.	Subsoil. No. 52.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Insoluble matter	38.46	36.06	39.02	42.60	33.73	34.53	42.08	42.78	38.78	39.74
Potash (K_2O)	.83	.74	.78	.81	.99	1.07	.65	.64	.83	.76
Soda (Na_2O)	.40	.42	.36	.44	.21	.38	.32	.37	.34	.47
Lime (CaO)	1.39	.86	.64	.60	.49	.37	.19	.21	.24	.26
Magnesia (MgO)	.55	.43	.41	.39	.52	.41	.35	.28	.64	.49
Manganese oxid (Mn_3O_4)	9.74	8.76	4.80	3.50	4.01	2.43	4.14	3.59	4.32	4.24
Ferric oxid (Fe_2O_3)	19.65	21.51	18.24	20.52	26.03	26.85	22.05	21.36	20.40	25.38
Alumina (Al_2O_3)	15.50	15.74	15.40	16.89	15.82	18.98	16.01	19.51	19.35	16.14
Phosphorus pentoxid (P_2O_5)	.21	.16	.36	.13	.35	.21	.13	.11	.11	.14
Sulphur trioxid (SO_3)	.16	.09	.23	.05	.17	.05	.37	.30	.29	.28
Titanic dioxid (TiO_2)	.73	1.09	.40	.58	.85	1.58	[1]	[1]	[1]	[1]
Loss on ignition	17.73	14.45	19.71	13.72	16.68	12.83	14.02	11.31	15.29	12.45
Total	100.35	100.31	100.35	100.23	99.86	99.69	100.31	100.42	100.59	100.35
Nitrogen (N)	.39	.23	.45	.19	.35	.20	.27	......	.24	.13

Constituents.	Normal soils.								
	Soil. No. 7.	Subsoil. No. 8.	Soil. No. 13.	Subsoil. No. 14.	Soil. No. 31.	Subsoil. No. 32.	Soil. No. 49.	Subsoil. No. 50.	Soil. No. 19.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Insoluble matter	40.89	39.25	46.52	46.37	41.73	37.16	42.36	39.82	44.00
Potash (K_2O)	.51	.60	.50	.57	.53	.57	.65	.48	.59
Soda (Na_2O)	.21	.32	.31	.13	.20	.37	.46	.20	.29
Lime (CaO)	.51	.66	.32	.31	.22	.15	.23	.12	.24
Magnesia (MgO)	.37	.38	.40	.42	.36	.30	.47	.44	.42
Manganese oxid (Mn_3O_4)	.22	.06	.33	.35	.22	.39	1.17	.36	.16
Ferric oxid (Fe_2O_3)	35.72	33.28	24.37	24.49	23.29	24.13	20.36	25.87	27.94
Alumina (Al_2O_3)	3.58	8.66	9.15	12.02	16.02	20.87	20.37	19.42	11.91
Phosphorus pentoxid (P_2O_5)	.07	.08	.09	.13	.08	.12	.10	.10	.04
Sulphur trioxid (SO_3)	.09	.07	.11	.12	.46	.33	.23	.42	.11
Titanic dioxid (TiO_2)	3.83	2.74	2.20	2.05	[1]	[1]	[1]	[1]	.28
Loss on ignition	14.22	13.99	15.98	13.17	17.22	16.38	13.22	13.33	13.95
Total	100.22	100.09	100.28	100.13	100.33	100.77	99.62	100.56	99.93
Nitrogen (N)	.34	.25	.38	.25	.29	.20	.27	.14	.29

[1] Titanium was not separated from alumina.

It is worthy of note that the manganiferous soils contain relatively more so-called plant food, and this, as will be shown further on, is

in a more soluble state. The mechanical analyses also show the difference that necessarily exists in physical properties. The percentages of clay are considerably higher in the red soil, while there is correspondingly more silt and fine sand in the manganiferous soils. The organic constituents are low in both alike, and the difference in color must be looked for in connection with the manganese rather than the organic matter. It should be noted that the black color of the manganese soil is not destroyed except by prolonged heating at a high temperature, when it becomes changed into a reddish brown by the driving off of oxygen from the manganese dioxid, thus converting it into mangano-manganic oxid. Upon treating the manganiferous soil with hydrochloric acid copious quantities of chlorin are evolved.

SOLUBILITY.

In investigating the functions of manganese in plant growth it is essential to know something of the form and solubility of the various substances in the soil. The mineral plant nourishment comes from the soil moisture, and the concentration and composition of this solution are known to exercise a direct influence on the growth of vegetation. It is, however, by no means easy to reproduce in analytical operations all the conditions that occur naturally in the fields. The soil moisture is a variable complex, which is constantly being further affected by the activities of bacteria in the soil and by the products of root growth and plant decay. Growing rootlets are known to have solvent powers that are not possessed by pure water, and in addition laboratory experiments at best are only approximations of natural processes and should therefore not be looked upon in any other light. Every step leading to a knowledge of the relative solubility of the substances in the soil, however, makes possible a better understanding of the process of absorption and assimilation, and therefore lie at the foundation of functional studies; for, as stated above, insoluble substances must be looked upon as chemically inert so far as vegetable growth is concerned.

With a view of throwing some light on this question, representative samples of soil were extracted with various solvents for a definite period at the ordinary temperature of the laboratory. The solvents employed were water, 1 per cent solutions of citric, oxalic, and acetic acids. In every instance 100 grams of air-dried soil were shaken at intervals for three days with 1,000 cubic centimeters of the solvent, then filtered and 500 cubic centimeters of the filtrate evaporated to dryness, incinerated, and the residue analyzed. The table following shows the results.

Solubility of manganiferous and normal soils.

MANGANIFEROUS SOILS.

Number of soil and solvent used.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxid (Fe_2O_3)	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Phosphoric acid (P_2O_5).
Laboratory No. 128:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Water soluble	0.00	0.0028	0.00	0.0018	0.0040	0.0012	0.0057	0.00
Citric acid soluble	.036	.440	.086	1.521	.209	.041	.035	Trace.
Oxalic acid soluble	.035	.498	.035	.952	Trace.	.032	(1)	Trace.
Acetic acid soluble	.025	.014	Trace.	.025	.351	.022	(1)	Trace.
Laboratory No. 129:								
Water soluble	.00	.003	.00	.0016	.0054	.0019	.0084	.00
Citric acid soluble	.036	.475	.113	1.692	.120	.046	.028	Trace.
Oxalic acid soluble	.045	.194	.039	1.248	Trace.	.003	(1)	Trace.
Acetic acid soluble	.023	.029	Trace.	.036	.167	.022	(1)	Trace.
Laboratory No. 125:								
Water soluble	.00	.002	.00	.0014	.004	.002	.007	.00
Citric acid soluble	.048	.527	.109	1.634	.138	.035	.050	Trace.
Oxalic acid soluble	.065	.373	.065	1.507	Trace.	.011	(1)	Trace.
Acetic acid soluble	.028	.021	Trace.	.026	.265	.024	(1)	Trace.
Laboratory No. 124:								
Water soluble	.00	.002	.00	.002	.003	.002	.008	.00
Citric acid soluble	.051	.626	.141	1.493	.142	.031	.034	Trace.
Oxalic acid soluble	.065	.370	.069	1.800	Trace.	.029	(1)	Trace.
Acetic acid soluble	.034	(1)	(1)	.029	.193	.019	(1)	Trace.

NORMAL SOILS.

Number of soil and solvent used.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxid (Fe_2O_3)	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Phosphoric acid (P_2O_5).
Laboratory No. 127:								
Water soluble	.00	.001	.00	.00	.005	.001	.005	.00
Citric acid soluble	.084	.288	.076	.014	.080	.003	.029	Trace.
Laboratory No. 126:								
Water soluble	.00	.001	.00	.00	.008	.002	.009	.00
Citric acid soluble	.039	.275	.134	.909	.080	.001	.024	Trace.
Laboratory No. 123:								
Water soluble	.00	.001	.00	.00	.004	.001	.006	.00
Citric acid soluble	.107	.347	.045	.165	.081	.002	.036	Trace.
Laboratory No. 7:								
Water soluble	.00	.001	.00	.00	.006	.001	.012	.00
Citric acid soluble	.045	.308	.099	.009	.040	.001	.030	Trace.

[1] Not determined.

The principal difference to be observed in the relative solubility of the manganese soil, as compared with normal soils, is in regard to the manganese, which is uniformly found to be more soluble than other constituents, especially in di- and tri-basic organic acids, such as oxalic and citric acids, which are known to have a solvent effect on manganese dioxid, with the formation of the corresponding proto-salts. Acids of the monobasic series, however, such as acetic, have much less solvent effects on MnO_2, being more difficult of oxidation, and consequently dissolved appreciably less manganese, although the amounts taken up are noteworthy.

The solubility of the manganese in water is of special interest, and the data show that if the absorbing surfaces of growing plants have no other nutrient media than that afforded by water in contact with this soil manganese would be available to them in dominant quantities. In addition to its bearing on the availability of the manganese, the solubility table also affords further evidences that point to the importance of the solubility factor in explaining the occurrence of the manganiferous areas.

PHYSICAL PROPERTIES.

From the standpoint of the physical composition and properties the manganiferous soil is superior to the general soils of the plateau. It contains less clay and more silt, consequently is tilled with less difficulty and maintained in a good pulverulent condition with far more ease. The heavy rains that frequent the section at times produce a baking and puddling of the red soils, which condition is almost entirely absent in the manganiferous soils, so that the texture of these soils is all that the agriculturist desires. Normal root development, so far as the texture is concerned, would therefore be expected to be superior in the manganiferous soil. The following table shows the physical composition of the two types:

Physical analyses of soils.

Kind of soil.	Manganiferous soils.		Normal soils.	
	Serial No. 9.	Serial No. 15.	Serial No. 7.	Serial No. 19.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Gravel	0.00	0.00	0.00	0.00
Fine gravel	.87	2.54	.00	.00
Coarse sand	8.20	6.28	.77	.60
Fine sand	22.44	21.17	3.64	2.31
Silt	13.64	14.57	8.85	6.79
Fine silt	23.13	21.90	34.54	38.42
Clay	13.61	15.50	36.28	37.58
Organic matter and combined water	16.77	16.66	13.14	13.35

From an examination of these data it is apparent that the circulation of air is freer in the manganese soil.

NITRIFICATION AND AMMONIFICATION.

With the view of determining the relative rates of nitrogen transformation taking place in the two classes of soil, samples were collected in sterilized containers, carefully protected from the direct influence of light, and used in nitrification and ammonification experiments. These experiments were carried out in large beakers, using 100 grams of soil with the addition of ammonium sulphate, in one series, and solutions of peptone in another, in quantities containing 100 milligrams of nitrogen per beaker. The soil was brought to a two-thirds saturation with sterilized water, and allowed to stand in the dark for a period of four weeks. Additional water was added at the end of each week in sufficient quantities to replace that lost by evaporation. At the end of this period nitrogen as nitrates and ammonia was determined in each sample. The results are recorded in the table following.

Nitrification and ammonification in soils.

Class of soil.	Milligrams of nitrogen in 100 grams of soil.				
	As nitrates.			As ammonia.	
	Original soil.	With the addition of ammonium sulphate.	With the addition of peptone.	Original soil.	With the addition of peptone.
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Normal soil, No. 127	0.66	1.68	1.44	2.80	90.22
Normal soil, No. 126	2.00	.50	2.08	2.00	87.70
Normal soil, No. 7	.72	.50	.80	2.20	87.98
Normal soil, No. C	1.00	1.24	1.00	2.80	84.06
Average, normal soils	1.09	.98	1.33	2.45	87.49
Manganiferous soil, No. 9	.40	5.00	2.00	5.60	86.30
Manganiferous soil, No. 15	.43	1.68	.80	4.20	83.44
Manganiferous soil, No. 128	.28	2.00	2.20	3.50	76.76
Manganiferous soil, No. 129	.47	1.25	1.80	3.10	84.62
Average, manganiferous soils	.40	2.48	1.70	4.10	82.78

It will be seen that nitrification took place more rapidly in the manganese soil, while ammonification was about equal in the two classes of soil. These results are in harmony with the physical composition of the soil. Aeration and consequent oxidation would be expected to take place more rapidly in the manganese soil, and the fact that nitrification is more active in the manganese soil may be taken as evidence of the noninterference in the growth of nitrifying and ammonifying bacteria by the manganese.

DISCUSSION AND CONCLUSIONS.

The manganiferous soils of Oahu are located on the upland plateau between the Waianae and Koolau Mountain ranges, at an elevation of from 650 feet to 900 feet. Their occurrence in local areas as surface accumulations in the alluvial sheet and never in the sedimentary strata below it is such as to indicate that the concentration of manganese has come about through the action of solution and leaching, followed by subsequent oxidation and deposition.

The normal lava, which is the original material from which all the soils of the islands are derived, contains manganese in greater quantities than does the decomposition residue arising from it. The drainage water from the mountains at the present time contains a small amount of manganese in solution, from which it becomes slowly deposited on the surfaces of objects in the streams. Manganese, therefore, becomes soluble in the normal weathering of the basaltic lavas of the islands. The occurrence of the manganiferous soil in the lower altitudes, etc., together with the fact that the manganese of the normal lava becomes soluble during weathering, indicates that the transfer and ultimate deposition of the manganese has been affected through the agency of water.

The occurrence of manganese concretions, the largest in size of which being some depth below the surface, and deposited in the lower levels in the alluvial sheet, but not in the sedimentary or residual soil, together with the sharp line of stratification separating the alluvial from the residual strata, indicate that there has been a submergence, during which time the deposition of the alluvial soil and the accumulation of manganese concretions took place. Subsequent leaching further accentuated the accumulation of the manganese in the lower places, especially in basins or at the bases of long slopes.

The solubility in weak organic acids shows that the availability of the manganese is relatively high and that manganese probably exists in the soil moisture and in solution around the absorbing surfaces of roots in greater quantities than any other element. Therefore it exists in just the condition to exert its full physiological effects on plants. The physical properties of the manganiferous soils are more nearly ideal than are those of red soils. They contain less clay, and more of the coarser particles. Consequently the circulation of air is greater in the manganese soil.

Nitrification and ammonification appear not to be influenced by the presence of manganese in the soil. That the former has been found to take place more advantageously in the manganese soil can probably be accounted for by the fact that the circulation of air is less obstructed in this type.

Acknowledgments are due and thanks are hereby extended to Dr. E. W. Hilgard for helpful suggestions in this work; and to Dr. E. V. Wilcox, who showed the greatest interest throughout this investigation, offered many suggestions, and in many ways rendered valuable assistance.

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Issued December 31, 1913.

HAWAII AGRICULTURAL EXPERIMENT STATION,
E. V. WILCOX, Special Agent in Charge.

Bulletin No. 30.

THE EFFECT OF HEAT ON HAWAIIAN SOILS.

BY

W. P. KELLEY,
Chemist,

AND

WILLIAM McGEORGE,
Assistant Chemist.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 15, 1913.*

SIR: I have the honor to submit herewith and recommend for publication, as Bulletin 30 of the Hawaii Agricultural Experiment Station, a paper dealing with the Effect of Heat on Hawaiian Soils, by W. P. Kelley, chemist, and William McGeorge, assistant chemist of the station. The effect of heat upon Hawaiian soils, including highly manganiferous soils, has been found to be decidedly beneficial to the growth of all kinds of plants. The careful study of the various chemical and mechanical changes produced in soils by the application of heat, as set forth in this bulletin, throws considerable light upon the reasons for this beneficial effect. Studies on the effects of heat on soils have usually been confined to a few plant-food elements, whereas in this bulletin a large number of the inorganic and organic substances are considered. The bulletin is, therefore, considered a distinct contribution to the literature of this interesting phase of soil work.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

THE EFFECT OF HEAT ON HAWAIIAN SOILS.

INTRODUCTION.

Heat as a means of stimulating crops has been made use of in certain European countries for centuries. The burning of moorlands and the paring and burning of heavy clay sods were extensively practiced in times past. Although their use at present is by no means as common as formerly, these practices have not been entirely abandoned. The adoption of more intensive methods of farming, the use of fertilizers, cost of fuel, recognition of the serious destruction of the organic matter, and the demand for a more continuous use of the land have brought about the gradual disuse of these ancient practices.

In America soil burning, in the sense it is understood in Europe, has never been made use of extensively. In connection with certain crops demanding early forcing, however, soil burning is practiced well-nigh universally. The seed of tobacco, cabbage in some localities, and some other crops that are grown from transplanted seedlings are still sown in soil which has been previously burned. In preparing seed beds for tobacco the soil is frequently burned heavily, usually a strong wood [1] fire being maintained on the bed for several hours. It is a matter of common observation that the growth of seedlings on the burned soil is usually superior to that on the surrounding unburned land. The effects of burning are by no means confined to the germination and growth of seedlings. In newly cleared lands crops of various kinds usually grow more rapidly and produce increased harvests on the spots where brush or log heaps have been burned, and often the effects persist through two or more years.

In Hawaii the growth of certain crops is enormously influenced by the mere burning of small accumulations of brush and undergrowths of guava and lantana. The effect on cotton on the uplands of Oahu produced by these small fires may represent the difference between success and failure. The color and vigor of the crop on these small areas dotted here and there over a field attract attention. Other crops are affected similarly.

[1] Oil and gas are sometimes used for this purpose.

It has been known for a long time that burning improves the structure of clays by causing a coalescence of the smaller particles into larger granules, thus effectively improving the drainage. The increased size of the pores and air spaces within the soil permits of better aeration and encourages deeper root development. By means of heat the hydrous compounds become dehydrated, plasticity and adhesiveness are overcome, the movement of soil moisture facilitated, and a more congenial environment for root development is produced. If sufficiently great heat be employed, the clay may be baked into hard lumps, which yield to cultural and weathering influences with difficulty, and, therefore, injury may result. In any event the dehydrated silicates and oxids return very slowly to their former state and the crumb structure induced by the heat persists for years. The physical effects of heat on clays are so pronounced that the admixing of a few tons per acre of the burnt with the natural soil was formerly employed in Europe as a means of ameliorating heavy clay lands.

Regarding the chemical effects of burning it is also well known that clay soils undergo chemical changes. In general the solubility of aluminum and potassium in acids is greatly increased up to a certain temperature, beyond which a decrease sets in. It is generally held that under the influence of high temperatures, especially with the aid of oxidizing conditions, a wasteful destruction of soil organic matter and consequent loss of nitrogen takes place.

In addition to the above-named physical and chemical effects the killing of weed seeds, parasitic fungi, disease-producing organisms, and insects are generally looked upon as being among the beneficial effects of soil burning.

While the old system of burning the soil has gradually fallen out of use, the closely related partial sterilization by means of heat and volatile antiseptics is of great interest at the present time. In greenhouse work steam sterilization finds extensive application and has been the subject of interesting investigations during the past few years. Likewise the action of dry heat in its relation to partial sterilization and in comparison with the effects of volatile antiseptics on subsequent biological activities has received considerable study. The old idea of considering the subject in a restricted physical and limited chemical sense is, therefore, giving way to a broader view of the question. The more specific chemical effects involved, including certain physico-chemical effects dealt with more in detail in this paper, and the biological results are now being studied.

It has been found that moderate temperatures bring about an increase in the solubility not only of the mineral constituents of soils but also in the organic matter. Furthermore, a number of investigators have found that steam sterilization, particularly when under

pressure, frequently produces a condition that is toxic both to the germination and the subsequent growth of plants. Usually the toxic condition is of short duration and the growth of crops seems to aid effectively in overcoming it. There are many phases of this question that are not fully understood.

There are two characteristics of Hawaiian soils that give them special interest in this connection, (1) the peculiarities and the high proportion of the clay; (2) the inertness of the unplowed and unbroken sod lands. The former gives special interest to the question of heating from the physical point of view, and the latter is of interest to the question because of its bearing on soil aeration. With but few exceptions it is necessary to plow the land, following with thorough tillage at frequent intervals for several months before planting. A field plowed for the first time, although the soil be thoroughly pulverized and reduced to a state of fine tilth, usually will not support plant growth satisfactorily. The farmers of Hawaii have found it necessary to aerate newly plowed lands for a period of several months before planting the first crop. It has been observed, however, that excellent growth of crops is obtained on the small spots where brush was burned and without the continued aeration above referred to. Heat, therefore, seems to accomplish in the soil effects similar to those brought about by aeration. The application of fertilizers produces no such effects.

In connection with a general study of soil aeration the authors have, therefore, been led to a study of the effects of heat on these soils. The present paper deals with one phase of this question, the physico-chemical changes produced. In the first part are presented the data obtained with reference to the solubility of the inorganic constituents and in the second part are some data of a more or less empirical nature on the grosser effects of heat on soil nitrogen.

THE EFFECTS OF HEAT ON THE SOLUBILITY OF INORGANIC CONSTITUENTS.

While a considerable number of investigators have studied the question of the effect of heat upon the solubility of phosphoric acid, using various solvents, apparently few have gone beyond this and determined its effect upon the solubility of the remaining mineral constituents commonly occurring in soils. In fact, with few exceptions, the entire stress has been laid upon the three elements generally considered to be of greatest plant-food value, namely, nitrogen, phosphoric acid, and potash.

In most instances the results of these earlier investigations have shown an increase in solubility of phosphoric acid, with increase in the temperature to which the soils have been heated. M. Nagaoka,[1] on

[1] Bul. Col. Agr., Tokyo Imp. Univ., 6 (1904), No. 3, p. 263.

igniting soils for 15 minutes to remove humus, found an increase in solubility of phosphoric acid, which, he concluded, was due to the destruction of organic matter with which the phosphoric acid was combined. He used as solvents, hydrochloric acid, specific gravity 1.15, distilled water, and several of the weaker organic acids. Stewart[1] used Schmoeger's method of determining the increase of solubility in 12 per cent hydrochloric acid before and after ignition, as an indication of the phosphoric acid combined with organic matter. Fraps,[2] while finding an increase in the solubility of phosphoric acid on ignition, considers that this increase is not wholly due to organic phosphorus, but that mineral phosphates in soils are also rendered more soluble by ignition, thereby rendering the ignition method an unsuitable one for determining organically combined phosphorus. On the other hand, Lipman[3] found while working on a series of California soils, that heating decreased the solubility of phosphoric acid in strong nitric acid. Peterson[4] found that the solubility increased rapidly with increase in temperature from 130° up to 200° C., but that the solubility of the mineral phosphates in soils was not increased by heating below 240° C.

Valuable work on the solubility of the mineral constituents of soils is to be found among the publications of the Bureau of Soils, the work being confined largely to the use of water as solvent. In a bulletin of that bureau,[5] King gives comparative results of work upon fresh and oven-dried soils which show the effect of heating to 110° C. to be striking. On the average more nitrates, phosphoric acid, sulphates, bicarbonates, and silica were recovered from the oven-dried soils than from the fresh samples, while the average of the chlorin determinations showed a decrease. No determination of the basic constituents are tabulated, but King states that upon later investigations he found an increase in potash, lime, and magnesia in oven-dried soils. He makes several suggestions as to the cause of this increase, both from a physical and chemical standpoint, but it is evident from his discussions that he considered the cause to be primarily physical. A number of other investigators have noted an increase in total inorganic matter soluble in water[6] as a result of heating, but no separation of the elements was made.

The special phase to which this paper is devoted is that of the effect of heat upon the solubility of the mineral constituents, distilled water and fifth-normal nitric acid being used as solvents.

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[1] Illinois Sta. Bul. 145.
[2] Texas Sta. Bul. 136.
[3] Jour. Indus. and Engin. Chem., 4 (1912), No. 9, p. 663.
[4] Wisconsin Sta. Research Bul. 19.
[5] U. S. Dept. Agr., Bur. Soils Bul. 26, p. 55.
[6] New York Cornell Sta. Bul. 275.

PRELIMINARY WORK.

The results of some preliminary experiments on three Hawaiian soils dealing with the various methods of preparing soil extracts with distilled water are presented in the following table:

Influence of state of moisture and time of extraction on composition of the water extract of soils.

[In parts per million of dry soil.]

	Length of extraction.	Bicarbonates (HCO_3.)	Iron oxid and alumina (Fe_2O_3 and Al_2O_3).	Phosphoric acid (P_2O_5).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Sulphuric acid (SO_3).	Potash (K_2O).
Soil No. 313:									
Fresh	1 hour	155.0	53.5	2.03	2.55	122.2	62.7	247.0	133.0
Air dried	do	1,040.0	8.7	1.95	17.4	121.8	103.0	120.0	256.0
Oven dried	do	358.0	12.8	2.35	....	197.0	159.0	194.0	143.0
Fresh	24 hours.	95.6	17.8	2.55	2.55	148.0	77.6	257.2	226.6
Air dried	do	678.0	13.0	1.74	15.20	86.8	102.0	134.5	213.0
Oven dried	do	246.0	19.2	3.42	....	120.0	126.2	199.0	121.0
Fresh	7 days	191.0	45.8	2.55	15.2	96.9	68.3	221.5	239.8
Air dried	do	562.0	44.5	2.38	88.9	160.5	168.0	171.0	282.0
Oven dried	do	262.0	49.1	3.00	....	102.2	116.0	145.0	61.0
Subsoil No. 314:									
Fresh	1 hour	97.8	38.6	2.32	2.5	56.5	14.8	114.0	150.5
Air dried	do	708.0	4.3	1.94	27.4	77.2	105.2	81.0	142.0
Oven dried	do	371.0	....	....	....	89.0	99.8	145.0	64.1
Fresh	24 hours.	117.7	43.7	2.32	5.1	77.0	39.0	175.6	208.5
Air dried	do	651.0	10.8	2.14	30.1	43.0	88.5	72.0	181.0
Oven dried	do	228.0	14.8	2.96	....	85.0	113.5	131.0	118.0
Fresh	7 days	157.0	23.2	2.05	12.8	71.9	70.4	137.1	227.0
Air dried	do	688.0	6.4	2.14	17.2	47.2	76.1	83.8	158.2
Oven dried	do	180.0	17.0	2.76	....	63.8	109.0	151.0	68.0
Soil No. 319:									
Fresh	1 hour	140.0	3.04	.76	1.52	127.6	60.2	137.1	142.2
Air dried	do	975.0	20.2	1.80	15.70	224.0	120.0	105.5	278.0
Oven dried	do	558.0	11.2	7.05	....	194.1	119.5	136.0	135.0
Fresh	24 hours.	200.0	4.6	1.37	4.6	197.6	105.1	133.7	170.8
Air dried	do	1,300.0	40.5	1.80	15.7	103.2	81.5	67.2	274.0
Oven dried	do	270.0	15.4	3.31	....	123.5	103.5	133.0	70.5
Fresh	7 days	99.0	10.3	1.06	7.6	206.7	55.0	155.6	155.0
Air dried	do	1,280.0	9.0	2.02	29.2	162.0	102.0	93.1	234.0
Oven dried	do	485.0	....	....	....	212.0	124.0	159.0	147.0

The soils chosen were from the Koolaupoko district, on Oahu, No. 313 being a sample of brown ferruginous clay soil which occurs widely distributed in this district. It was very dry at the time of sampling and was covered with a heavy growth of guava. No. 314 is the subsoil to No. 313, and No. 319 is a sample of a similar type which had been plowed and planted to pineapples.

The extracts were made by treating the soils with distilled water in the proportion of 5 parts of the latter to 1 of the former in glass-stoppered bottles, shaking occasionally during the period noted in the table, each being shaken an equal number of times. The values are figured to parts per million of the oven-dry soil. Sample No. 313 contained, originally, 18.65 per cent moisture, No. 314 19.65 per cent, and No. 319 30.3 per cent.

It will be seen that in every case the air-dried soil contained the largest amount of soluble HCO_3, the oven-dried sample next, and the fresh soil the least, regardless of the time of extraction.

No attempt was made to separate iron oxid and alumina, but the determination seems to vary considerably in the different soils. No. 313 apparently increased in solubility with increase in time of extraction. If the abnormal figure, 53.5, be disregarded, the difference between the fresh, air-dried, and oven-dried soil is very slight. In the subsoil air drying produced a decrease in solubility, but the oven-dried were more soluble than the air-dried samples. The results from No. 319 are discordant, but indicate the air-dried form to be the most soluble.

Phosphoric acid.—This series is remarkably concordant and indicates an increase in solubility of this constituent upon drying in the oven and at the same time, without exception, shows an increase in solubility with increase in time of extraction.

Manganese.—These results indicate an increase in solubility of manganese with increase in time of extraction and also an increase in solubility upon drying. Unfortunately the whole series of manganese determinations on the oven-dried samples was lost through accident.

Lime.—While the results from the lime determinations are very inconsistent, the general average tends to show an increase in solubility upon heating in the oven and a maximum solubility in the one-hour period of extraction. This latter may be due, however, to subsequent precipitation in the longer extractions.

Magnesia.—The table shows a marked consistency, especially with reference to the rate of increase in solubility of magnesia, due to drying. The concentration of the extracts from the fresh soils was least, with only one exception, while that from the oven-dried soils was greatest in most instances. While there is considerable variation, the data indicate the most complete extraction in that of seven days' duration.

Sulphuric acid.—The relative amounts of this constituent extracted show it to be slightly more soluble in the fresh soil, judging from the average of the series, although only slightly more so than in the oven-dried soil, and that the concentration is practically the same for the several periods of extraction.

Potash.—The potash series shows this element to be much more soluble in the air-dry and fresh soils than in the oven-dried soils, while there is scarcely any difference in the solubility as induced by increasing the time of extraction from 24 hours to 7 days.

The above results tended to establish the advisability of an arbitrary extraction of not over 24 hours, and partly for this reason it was decided that the method at present in general use, namely, shaking for a period of 1 hour and allowing to settle for 24 hours would be suitable to our conditions. Owing to the mechanical texture of Hawaiian soils, caused by the presence in them of highly ferruginous clays, which assume a colloidal form if worked when too wet, it was found necessary to allow the extracts to settle and in every instance, except when heated to 250° C. or ignited, it was necessary to add a

coagulant. Not having the apparatus to effect a rapid filtration through clay filters, small amounts of ammonium chlorid were used to bring about coagulation of the clay and make filtration through filter paper possible. In addition to using distilled water as a solvent, fifth-normal nitric acid was chosen in order to gain additional information concerning the action of different solvents. The means chosen for drying the soils were in an air bath at 100° C., and 250° C., over a Bunsen burner. It being practically impossible to obtain ignition all the samples fresh, extraction upon the soils in this state was not attempted.

METHOD OF PREPARING EXTRACTS.

The soils were prepared as follows: Upon receipt in the laboratory they were spread out to dry. After reaching an approximately stable moisture content portions were weighed into porcelain dishes. One series was dried in an oven at 100° C. for 8 hours continuously, another treated likewise at 250° C., while the last series was heated over a Bunsen burner, at first carefully on a wire gauze for 2 hours to prevent dusting and then over the direct flame for 2 hours, thus destroying practically all the organic matter.

Water extract.—This extraction was made by treating 200 gram portions of the soils with 1 liter distilled water, shaking occasionally for 1 hour, as previously mentioned, and then allowing to settle 24 hours, adding small amounts of ammonium chlorid as a coagulant when necessary. Particular attention was given to these extractions in order that all the samples in each series of the same soil should receive similar treatment as regards the number of times of shaking, thus making the results more directly comparable. Likewise, all distilled water for a series was taken from the same lot in order to eliminate any slight influence which varying amounts of carbon dioxid in the distilled water would have upon the solubility of the minerals. After settling 24 hours the solution was filtered through double filter papers and from this solution 500 cubic centimeters was evaporated to a small volume and used for analysis. All determinations were made gravimetrically except phosphoric acid, iron, and bicarbonate. The former was made colorimetrically in 50 cubic centimeters of the original solution.[1] Iron was determined colorimetrically[2] in a solution of the ammonia precipitate from the 500 cubic centimeters portion, and bicarbonate was determined by titrating 50 cubic centimeters of the original solution with twentieth-normal acid potassium sulphate, using methyl orange as indicator.

Nitric acid extract.—The soils for this phase of the work were prepared in the same manner as above described as regards tempera-

[1] U. S. Dept. Agr., Bur. Soils Bul. 31, p. 45.
[2] U. S. Dept. Agr., Bur. Soils Bul. 31, p. 38.

tures and time of heating. However, in this work only 100 grams were treated with 500 cubic centimeters fifth-normal nitric acid. The extraction differed in that the soils were shaken occasionally, for a period of 5 hours, and then filtered directly through double filter papers. All determinations were made gravimetrically in 100 cubic centimeters of this filtrate with the exceptions of iron, which was determined volumetrically, and phosphoric acid and titanium, which were determined colorimetrically in 25 cubic centimeter portions of the original extract.

SOIL TYPES.

The types of soil selected for this work were of the widest possible range, and represented, in a general way, the normal and abnormal types, both physical and chemical, to be found in the islands. The following table gives the chemical analyses of samples as determined with hydrochloric acid of specific gravity 1.115:

Chemical analyses of soils used.

	Soil No. 74.	Soil No. 164.	Soil No. 9.	Soil No. 292.	Soil No. 290.	Soil No. 405.	Soil No. 416.	Soil No. 417.	Soil No. 406.	Soil No. 428.	Soil No. 426.	Soil No. 448.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Moisture (H_2O)	25.46	1.22	5.36	7.65	8.44	8.02	6.17	16.26	10.34	14.94	10.47	16.00
Volatile matter	13.08	3.56	16.78	8.42	15.80	12.50	17.73	17.53	17.73	22.24	18.28	25.58
Insoluble matter	32.69	48.17	31.67	38.49	40.02	39.12	36.09	30.92	37.31	34.99	24.80	15.10
Iron oxid (Fe_2O_3)	10.13	30.58	18.60	16.63	16.41	15.24	13.20	11.24	10.92	8.24	22.52	19.20
Alumina (Al_2O_3)	12.59	3.05	14.67	12.85	14.11	20.54	20.39	19.38	20.20	10.73	19.10	16.64
Titanium oxid (TiO_2)	......	1.72	.68	2.00	1.50	2.40	1.60	1.40	1.80	3.20	3.80	4.20
Manganese oxid (Mn_3O_4)	.13	.10	9.21	.24	.30	.15	3.84	2.85	.06	.20	.22	.06
Lime (CaO)	2.63	.12	1.32	1.84	.77	.86	.33	.21	.48	1.91	.15	.50
Magnesia (MgO)	1.09	1.22	.52	8.71	1.30	.99	.44	.36	.67	2.24	.44	1.80
Potash (K_2O)	.14	.48	.79	.39	.17	.20	.39	.45	.20	.24	.28	.15
Soda (Na_2O)	.34	1.46	.38	1.36	.42	.48	.59	.36	.48	1.40	.74	.68
Sulphuric acid (SO_3)	.22	.44	.15	.08	.10	.33	.35	.43	.30	.45	.39	.53
Phosphoric acid (P_2O_5)	1.02	.08	.20	.57	.27	.44	.20	.24	.48	.22	.19	.29

No. 74 is a yellowish-brown soil from Waimea, Hawaii, of sandy silt texture, with an abnormally low clay content, and maintains a very loose, open structure.

No. 164 represents a peculiar type of soil more or less scattered over the islands, which upon absolute analysis shows about 20 per cent of titanium oxid. It is high in iron and aluminum, and also contains a larger percentage of ferrous iron than any of the soils examined heretofore. It has a high specific gravity, bluish-gray color, packs quite closely, has a "clayey silt" texture, and contains an abnormally low content of moisture and organic matter.

No. 9 is a sample of the highly manganiferous type found in the Wahiawa district on Oahu. It has a chocolate-brown color, a sandy silt texture, and maintains an excellent mechanical condition, thus permitting good aeration.

No. 292 represents the type of soil occurring in the lowlands in and about Honolulu now being used for bananas, rice, and truck farming. It has a sandy texture, grayish-brown color, and abnormally high magnesia content.

No. 290 is a peculiar type of soil occurring in the valley on the experiment station grounds, and is undoubtedly of sedimentary origin, its nature being largely determined by washings from the mountain. It is a blue clay soil, exceedingly plastic when wet, but upon drying forms hard compact lumps, and is somewhat similar to adobe or gumbo soils. This soil also has a soapy feel, and during the rainy season aeration and drainage are almost impossible.

Nos. 405 and 406 are samples of a silty soil, to be found in the Kalihi district of Honolulu, which is being used for aquatic agriculture, the former for rice, the latter for taro culture.

Nos. 416 and 417 represent the type of red clay soil which is so abundant on all the islands. These samples were taken only a short distance apart with the view in mind of determining the effect of cultivation, 416 being a cultivated soil, while 417 is practically the same soil from the unbroken sod.

No. 428 is a sample of highly organic, dark-colored soil from Glenwood, Olaa district, Hawaii. It has a very sandy texture and is subjected to heavy rainfall and good drainage, but for some reason, probably climatic, is unproductive.

No. 426 is a sample from Kealia, Kauai, and represents a brown type of soil which has partly undergone a recementation of the particles into a yellow soft rock, hence the sample contains considerable gravel.

No. 448 represents the type of yellow clay scattered throughout the islands in certain districts, this sample having been taken from near Hilo, Hawaii.

The relative solubility of the various constituents is shown separately in order to bring out more clearly the effects of heat, one table being devoted to each element.

SILICA.

The following table shows the results obtained in the study of the effect of heating on the solubility of the silica:

Solubility of silica in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	35.3	13.0	8.7	8.7	0.196	0.187	0.113	0.225
164	10.0	2.0	3.0	4.0	.007	.006	.027	.067
9	8.5	9.5	8.5	7.4	.115	.091	.084	.190
292	4.2	8.3	7.2	10.3	.162	.580	.616	.523
290	2.2	2.1	17.2	8.6	.150	.148	.264	.596
405	2.3	6.9	5.7	16.1	.180	.219	.240	.267
416	12.5	7.8	7.8	10.4	.065	.055	.077	.192
417	2.4	10.5	9.4	22.3	.076	.076	.097	.206
406	4.6	4.5	31.2	33.5	.165	.173	.301	.292
428	15.9	14.9	8.9	11.9	.289	.261	.202	.329
426	1.15	3.38	7.9	1.13	.024	.009	.062	.158
448	0.0	0.0	0.0	8.0	.211	.226	.077	.327

The results of the silica determinations in the water extract are rather inconsistent, but the average shows the highest solubility at ignition. It will be observed that the data obtained with fifth-normal nitric acid disclose some very interesting facts which show that an increase in solubility of silica in dilute nitric acid in Hawaiian soils is produced upon heating to ignition. Furthermore, the tendency points toward a general increase in solubility with increase in temperature. Attention is called to the fact that the soils high in magnesia show the greatest solubility of silica in dilute nitric acid. An exception in this particular is found in sample No. 164, a soil almost devoid of organic matter and containing a very high titanium, iron, and silica content. A further discussion of these results will be taken up following the table of alumina determinations in consideration of the relation of these two elements in the soil.

ALUMINA.

The following table shows the results obtained in the determinations of alumina in heated and unheated soils:

Solubility of alumina in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	11.1	3.2	10.3	22.3	0.291	0.292	0.318	0.956
164	7.5	9.5	9.5	5.0	.060	.048	.139	.288
9	4.8	1.1	9.5	3.7	.583	.675	.676	1.034
292	16.6	17.6	14.5	17.1	.874	.598	.584	1.055
290	19.1	12.7	12.8	17.7	.266	.292	.691	.749
405	7.6	13.8	17.6	12.2	.169	.133	.444	.897
416	17.6	12.8	16.1	20.9	.420	.509	1.057	1.515
417	15.3	9.0	4.8	28.9	.679	.661	1.413	1.495
406	10.3	19.6	28.5	38.0	.295	.314	.882	1.425
428	4.4	6.3	11.9	8.8	2.261	2.031	2.208	2.244
426	2.9	6.6	1.7	2.1	.308	.347	1.192	1.571
448	4.9	.7	5.8	2.6	.979	1.757	1.966	2.757

It will be observed from this table that the alumina is affected in very much the same way as the silica. The results, while somewhat inconsistent, show an increase in water-soluble alumina in the heated soils, the number showing increase of alumina by heating from 100 to 250° C., being about the same as in passing to ignition. The effect of heat upon the solubility of this element in dilute nitric acid is very marked and increases regularly with increase in temperature. There is scarcely any correlation between the solubility of the alumina and the total amount of silica present. However, it is worthy of note that there seems to be a relation between the solubility of the alumina in dilute nitric acid and the volatile matter (organic matter and combined water) existing in the soil, as will be readily seen from the

table. Soil No. 164 is almost devoid of organic matter and combined water and contains the least soluble alumina, while, on the other hand, those soils in which the volatile matter is highest contain the most soluble alumina, this being especially noticeable in soils Nos. 428 and 448.

The effect of heat upon the solubility of alumina and silica, especially in water, is probably referable to a number of causes. It is believed, however, to be primarily physical, being related to an alteration of the films surrounding the soil particles and to a modification of the colloidal forms which these elements probably assume under the prevailing conditions. The former effect will be discussed in greater detail farther on. Dehydration and certain chemical alterations at the higher temperatures would, on the other hand, tend toward increasing the solubility in acids through the action of heat upon the hydrated silicates. It has long been known that certain aluminum silicates become more soluble in acids as a direct effect of heat. In the early manufacture of alum advantage was taken of this fact.

IRON.

The relative amounts of iron (Fe_2O_3) recovered by the two solvents appear in the following table:

Solubility of iron in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	17.6	9.7	9.2	12.5	0.003	0.002	0.006	0.055
164	3.5	3.5	3.5	5.1	.005	.007	.083	.047
9	3.7	5.3	3.9	4.5	.007	.016	.006	.006
292	2.9	5.3	3.1	3.5	.194	.037	.037	.013
290	4.8	3.2	4.4	1.8	.069	.069	.142	.046
405	6.4	9.2	5.4	5.1	.324	.302	.290	.157
416	2.8	2.8	2.8	2.5	.032	.032	.027	.015
417	5.2	2.7	3.3	3.8	.026	.029	.029	.033
406	4.6	2.7	4.0	2.1	.515	.487	.333	.158
428	1.9	2.7	3.2	1.6	.024	.033	.039	.107
426	1.7	1.3	1.6	1.3	.037	.061	.014	.082
448	2.1	3.2	2.3	2.1	.051	.038	.077	.024

Again, there is considerable inconsistency in the results, but an average shows the solubility of iron in water to be greatest in the air-dried soil. The solubility in dilute nitric acid is much less consistent than that in water, thereby making it impossible to advance any conclusions except to call attention to the fact that the alumina in Hawaiian soils is very much more soluble, both in water and in dilute nitric acid, than is the iron. But if the results from samples Nos. 292, 405, and 406 be disregarded, and this is plainly permissible since these soils are used in aquatic agriculture and the major part of the soluble iron is in the ferrous condition and would be oxidized

to the ferric condition on being heated to higher temperatures, thus becoming less soluble, then the figures show a marked increase in solubility of the iron with increase in temperature. It will be noticed that the three soils which it is proposed to disregard in drawing conclusions show a markedly regular decrease in solubility of the iron from the air-dried to the ignition state. A qualitative test of the water extract from these three soils showed a very high concentration of ferrous iron from the wet and air-dry samples. In several of the samples in the series there is a close correlation between the effects of the heat on iron and alumina, but it is by no means general.

Iron, alumina, and silica are apparently the constituents least soluble in water. The greater solubility of iron in the air-dried soil may be explained by the fact that the normal mechanical condition of Hawaiian soils is conducive to reducing conditions which result in the formation of small quantities of ferrous compounds. Hawaiian soils, although characteristically basic, normally give an acid reaction, due indirectly to the high clay content and its accompanying poor aeration. Magnification of this condition is to be found in the rice and taro soils, as will be shown in a later table (p. 24), in which soluble iron is found in comparatively large amounts. In such cases it is to be expected that the direct effect of heat would be to oxidize the iron and thus render it less soluble. Further confirmation of this theory is found in the cultivated and uncultivated soils (Nos. 416 and 417, respectively), in which the iron content of the latter is shown to be the more soluble. After heating at 100° the solubility in many instances is greater than in the air-dry samples and is probably due to physico-chemical effects upon the soil films and hydrated silicates. These latter effects are also responsible for the increased solubility of iron in dilute nitric acid as a result of heat.

MANGANESE.

The results obtained from the manganese (Mn_3O_4) determinations are shown in the following table:

Solubility of manganese in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	26.5	30.4	30.4	30.4	0.063	0.041	0.217	0.071
104	9.0	11.0	10.0	9.0	.003	.008	.013	[illegible]
9	23.5	26.5	25.5	20.1	.494	.669	1.692	1.129
292	5.2	4.1	41.4	14.5	.070	.098	.106	.067
290	29.4	20.4	40.8	45.1	.049	.076	.115	.118
405	5.9	10.3	14.9	18.4	.062	.062	.047	.041
416	2.2	4.5	14.4	14.8	.349	.529	1.314	.739
417	15.7	58.7	180.5	219.2	.385	.580	1.052	.748
406	9.1	4.4	6.0	9.6	.035	.030	.048	.040
428	15.9	161.1	32.8	6.3	.094	.102	.225	.135
426	6.9	9.0	90.3	33.8	.004	.012	.040	.023
448	2.8	13.4	108.7	119.6	.028	.032	.126	[illegible]

This table shows that the solubility of manganese in water is much greater in the heated soils, being most soluble in the ignited samples. The surprising feature of this table is the fact that several of the soils in the series show manganese in a much more soluble form than the manganiferous soil containing 9.21 per cent total Mn_3O_4. A possible explanation is found in the results upon the cultivated and uncultivated soils (Nos. 416 and 417, respectively), namely, that cultivation and the accompanying aeration has the effect of producing a lower state of oxidation or other changes which render the manganese less soluble in water. An observation of Nos. 416 and 417 (cultivated and uncultivated) shows a large decrease in solubility as a result of cultivation, and the highly manganiferous soil (No. 9) has been in cultivation for some time.

The table showing the solubility of manganese in dilute nitric acid presents a remarkably consistent series of results, as is shown by the increase in solubility as a result of the action of heat up to 250° C., followed by a large decrease as effected by ignition. This is true with only two exceptions in the entire series.

It is difficult to explain the effects of heat upon the solubility of manganese. This element occurs in some Hawaiian soils as concretions, especially in the highly manganiferous soils, and is present, at least partially, as manganese dioxid. But in the normal types concretions are absent, and here the manganese probably exists largely in a lower state of oxidation, and hence in a more soluble form. In any case manganites and salts may occur to a limited extent. As already noted, the soils heated to 250° C. and ignition gave the more concentrated water extract, an average indicating the maximum concentration from the ignited soils. The effect of heat upon the physical properties is probably the prime factor which influences the solubility in water. With one exception the oxids of manganese are quite insoluble in nitric acid, this oxid being manganous oxid (MnO). Therefore the higher oxids, such as manganomanganic oxid (Mn_3O_4) and manganic oxid (Mn_2O_3), which are both essentially combinations of manganese dioxid and manganous oxid,[1] are soluble in nitric acid to the extent of their MnO content, while their MnO_2 content remains insoluble. Consequently the solubility of manganese oxids increases with increase in heat owing to the above-mentioned decrease in state of oxidation, as high temperatures convert MnO_2 into Mn_3O_4 and Mn_2O_3, each of which is partially soluble in nitric acid. Therefore heat would tend to increase the solubility in nitric acid of that portion occurring as MnO_2.

In addition, it is known that the action of heat upon organic compounds of manganese and also certain of its salts converts them into

[1] $Mn_3O_4=2\ Mno+MnO_2$; $Mn_2O_3=MnO+MnO_2$. Hence it may be observed that Mn_3O_4 contains the more soluble manganese.

oxids. Then, apparently the more soluble oxid, Mn_3O_4, is formed in greater amounts when the soil is heated to 250° C.

LIME AND MAGNESIA.

The two tables below show the effects of heat upon the solubility of lime and magnesia:

Solubility of lime in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	176.8	330.6	2,801.1	1,039.5	2.312	2.332	2.131	1.427
164	28.1	44.2	64.3	38.1	.026	.030	.024	.024
9	224.9	302.9	910.9	766.8	.448	.909	.511	.323
292	112.6	86.9	242.3	207.1	.147	.856	.986	.674
290	183.0	232.1	195.6	206.3	.378	.406	.318	.876
405	296.9	133.3	363.0	261.9	.344	.362	.330	.316
416	82.2	107.3	270.6	232.6	.159	.158	.124	.108
417	26.5	98.5	330.5	332.9	.174	.174	.167	.136
406	57.1	93.9	697.5	547.7	.388	.409	.329	.191
428	184.4	1,455.6	1,509.3	220.6	.466	.479	.395	.368
426	16.1	33.8	225.8	106.1	.056	.083	.056	.058
448	59.2	67.1	763.6	708.6	.248	.252	.226	.162

Solubility of magnesia in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	75.1	73.9	182.7	63.1	0.121	0.123	0.138	0.096
164	50.2	42.2	60.2	44.2	.019	.020	.021	.019
9	96.4	99.5	167.3	150.4	.071	.066	.081	.049
292	83.4	91.1	136.7	130.5	.150	.359	.344	.197
290	285.2	385.2	230.3	192.6	.500	.522	.301	.283
405	209.7	130.9	151.6	147.0	.206	.204	.140	.060
416	105.1	127.5	140.9	127.5	.073	.062	.042	.046
417	67.5	126.6	189.8	157.1	.071	.073	.049	.062
406	82.2	87.2	234.7	245.9	.204	.226	.115	.098
428	152.6	366.8	268.4	134.2	.114	.107	.082	.079
426	34.6	47.4	158.1	108.4	.047	.040	.041	.044
448	57.8	77.8	297.9	303.3	.074	.064	.048	.048

The series of lime determinations shows that this constituent is most soluble in water in the soils which were heated to 250° C. and least soluble in the air-dried soils. This is true of every sample except one (No. 290), this latter being a peculiar adobe type of soil from the experiment station grounds. In dilute nitric acid it will be observed that lime is most soluble in those soils heated to 100° C., and, unlike the water extractions, the least concentration is obtained from the ignited soils. Thus it is shown that the action of nitric acid in no way correlates with that of distilled water. However, the results show the more highly organic soil to contain lime

in such form as to be more soluble in weak solvents, No. 164, a mineral soil, being the least soluble. Attention is also called to the effect of cultivation or aeration upon the solubility of lime and magnesia, namely, that the cultivated soils contain these elements in far more soluble form.

From a study of the table of magnesia determinations it is evident that the action of the solvents upon this element is quite similar to their action on lime as regards the effects of heat, but that the lime is very much the more soluble both in water and in dilute nitric acid. The results of the extractions with water show a maximum solubility in the samples heated to 250° C., the least soluble magnesia in the air-dry samples. This exactly correlates with the results of the lime determination. The solubility in dilute nitric acid does not correspond so closely, but the general tendency is similar in that the air-dry samples and those dried at 100° C. contain this element in the highest state of solubility, while in the ignited soils it is least soluble. An important fact to which attention is called is that, although most of the soils in this series show from digestion with hydrochloric acid (1.115 specific gravity) a higher magnesia content than lime, one of them four times as much, yet the lime, with very few exceptions, is considerably more soluble. One exception is to be found in sample No. 290, which represents a soil having a characteristic soapy property indicating the presence of hydrous magnesium silicate.

The effect of heat on the solubility of lime and magnesia is more striking than in case of the other elements. It is highly probable that the increased concentration of the water extract of the soil heated to 100° C. over the air-dried sample is produced through physical causes, namely, destruction of the soil film and dehydration accompanied by a slight decomposition of organic matter. On the other hand, the soil when heated to 250° C. undergoes more completely all the above transformations as well as decomposition of organic matter. Since calcium and magnesium are two of the elements universally combined with organic matter, there necessarily follows an increase in solubility as a result of the more complete decomposition. The soils showing the greatest solubility of these elements in water were those containing the highest organic matter.

The decrease in solubility of lime and magnesia in water and in nitric acid at 250° C. and ignition is hard to explain. It is undoubtedly partly due to chemical changes in the soluble forms resulting from the decomposition of the organic matter and is also influenced by the decrease in exposed surfaces as a result of an aggregation of the soil particles and probably other physical factors. It is suggested that one of the chemical changes taking place as a result of heat is that of a replacement of the potash and soda in the silicates by

magnesia and lime, more particularly the latter. The data in the tables show a decrease in solubility of lime and an increase in that of potash upon ignition in a majority of the samples. In addition to the above-mentioned factors a decrease in solubility after ignition would be produced by the conversion of the bicarbonates into normal carbonates, the former of which are more soluble than the latter. This would, of course, be most striking in the water extracts.

POTASH.

The following table shows the relative effects of heat upon the solubility of potash:

Solubility of potash in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	128.2	117.4	339.3	217.5	0.053	0.066	0.050	0.068
164	64.3	82.3	40.1	132.5	.027	.032	.026	.071
9	117.8	192.7	301.9	260.6	.073	.081	.064	.113
292	77.2	76.3	118.0	83.8	.061	.155	.202	.134
290	87.1	92.4	90.6	77.4	.177	.142	.054	.094
405	96.6	55.1	45.9	43.6	.056	.084	.095	.090
416	98.2	96.2	78.3	147.6	.055	.056	.038	.062
417	60.3	100.8	77.4	140.6	.061	.054	.038	.072
406	36.5	49.2	19.4	78.2	.014	.013	.032	.022
428	244.8	202.8	353.5	220.7	.038	.051	.029	.041
426	43.8	58.7	56.4	182.9	.025	.024	.030	.070
448	119.8	107.4	64.4	59.0	.032	.032	.033	.053

The figures show that the effect of heat upon potash is slightly different from the effects on lime and magnesia. The ignited soils appear to contain this element in the most soluble form, while the samples dried in air and at 100° C. contain it in the least soluble form. In the air-dried samples potash is also more soluble in the cultivated than in the uncultivated soil, and the greatest solubility of this element is also found in the highly organic soils.

Soils in general possess fixing power for potash and for phosphoric acid in particular. The fixing of potash is generally believed to be due to hydrated silicates and organic matter. Cameron and Bell [1] on continuously extracting a soil with water until no more potash dissolved, then grinding the sample and reextracting, found an additional amount of potash to be removed. This they attributed to a colloidal aluminum silicate upon the surface of the particles, thus protecting them from the action of the water as well as absorbing the potash. Dehydration and decomposition would therefore materially overcome the fixing power, and the potash replaced by lime or magnesia would not be refixed during a short period.

[1] U. S. Dept. Agr., Bur. Soils Bul. 30, p. 26.

PHOSPHORIC ACID.

In the next table are shown the results of the action of heat on the solubility of phosphoric acid.

Solubility of phosphoric acid in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	39.8	69.6	58.7	32.6	0.007	0.008	0.024	0.043
164	24.1	36.1	16.1	15.1	.005	.006	.007	.009
9	17.1	44.5	52.9	32.8	.007	.007	.011	.013
292	21.9	26.9	23.8	22.8	.058	.018	.020	.053
290	22.9	36.5	25.8	27.9	.006	.016	.020	.031
405	27.1	31.0	33.0	25.3	.011	.014	.027	.021
416	36.5	43.6	49.2	51.4	.005	.007	.007	.006
417	54.3	52.7	46.8	39.8	.005	.008	.009	.005
406	23.4	35.7	21.2	23.4	.024	.030	.064	.047
428	25.6	38.7	26.8	23.8	.011	.013	.012	.014
426	25.4	24.8	27.1	27.1	.008	.012	.011	.013
448	29.6	36.2	37.6	28.1	.028	.028	.036	.020

It may be seen from this table that the solubility of phosphoric acid is materially affected by heat, the solubility in water being greatest in the soils heated to 100° and 250° C., if it be permissible to draw conclusions from the general averages, while it is least soluble in the air-dried soils. It is also worthy of note that this element is more soluble in the uncultivated than the cultivated soil, the former, however, decreasing with increase in heat. In the extractions made with dilute nitric acid the average indicates a greater solubility in the ignited soils, the solubility tending to increase with increase in temperature.

Phosphoric acid exists in soils in major part combined with iron, aluminum, magnesium, and calcium, and is also found combined with organic matter, being always present in the so-called humus of soils. It may be in the form of basic phosphates, hydrogen phosphates, or as complex phosphates in combination with more than one element. It is probably combined mostly with iron and aluminum and titanium in Hawaiian soils. Considerable work has been done upon the effect of heat upon the solubility of this constituent and several attempts have been made to draw conclusions from these results as to its state of combination; that is, whether organically or inorganically combined. Peterson [1] using fifth-normal nitric acid found that after oxidizing the organic matter with hydrogen peroxid there was no increase in the solubility of phosphoric acid when the soil was heated to 240° C. He concluded, therefore, that the solubility of mineral phosphates in soils is not increased up to 240° C. The author's results tend to indicate a decrease in solubility of phosphoric acid at high tem-

[1] Wisconsin Sta. Research Bul. 19.

peratures, due either to a chemical change in its combination to a form less soluble in water or an increase in the absorbing power of the soil. The increase effected at 100° and 250° C. is undoubtedly partly due to destruction of organic matter and to the breaking up of the colloidal film. The action of dilute nitric acid is somewhat different, in that an increase in solubility upon ignition accompanies that of iron, alumina, silica, and titanium. Iron and aluminum in Hawaiian soils occur in the form of hydrates to a certain extent and are more or less impregnated with the phosphoric acid and titanium oxid, not only holding them in chemical combination, but also mechanically. The effect of heat would directly increase the solubility of these constituents in dilute nitric acid gradually up to the point of ignition, at which point the decomposition of the hydrates would be at a maximum. Changes due to the destruction of organic matter would cause an increase in the solubility of this element. Another factor of some importance in this connection is that of precipitation subsequent to solution. The increased solubility of aluminum and manganese would probably produce some precipitation of phosphoric acid, particularly in the water extract.

SULPHATES.

The following table shows the solubility of sulphates (SO_3) as affected by heat:

Solubility of sulphuric acid in water and fifth-normal nitric acid.

[Calculated on basis of dry soil.]

Soil No.	Soluble in water (parts per million).				Soluble in fifth-normal nitric acid (per cent).			
	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.	Air dry.	Dried at 100° C.	Dried at 250° C.	Ignited.
74	172.4	130.5	1,961.6	1,309.2	0.027	0.019	0.106	0.067
164	72.3	66.2	206.7	168.6	.037	.031	.027	.025
9	111.4	146.2	1,339.7	1,294.4	.017	.019	.053	.034
292	164.7	159.5	722.5	532.3	.067	.018	.019	.055
290	100.2	176.2	1,128.3	799.5	.022	.026	.062	.063
405	129.6	149.3	942.0	583.6	.018	.016	.067	.048
416	59.4	100.6	702.3	664.3	.028	.035	.038	.041
417	98.9	103.1	872.1	926.0	.032	.032	.037	.052
406	260.3	326.4	1,555.9	1,479.9	.061	.086	.163	.187
428	494.8	2,123.7	2,598.0	680.1	.089	.073	.101	.177
426	46.2	54.2	119.7	241.6	.018	.034	.019	.024
448	110.0	107.4	1,621.3	1,575.7	.028	.029	.044	.122

It will be seen from this table that the effect of heat upon the solubility of the sulphates is quite marked, more so in the water extracts. In this series the air-dried soil is the least soluble, that dried at 100° C. next, while the maximum solubility is reached at about 250° C., decreasing upon ignition. On the other hand, the solubility in dilute nitric acid is slightly different in that the average shows the maximum solubility to be obtained from the ignited samples, the least soluble being in the oven-dried (100° C.) soil. The surprising feature of these results is the markedly greater solubility of sulphates in water than in

nitric acid as shown in a number of instances. This is probably due to precipitation subsequent to extraction in the nitric acid extracts.

Part of the increase in the solubility of sulphates in the heated soils of this series was probably due to absorption of the products of combustion of the gas used in heating the oven. It was found that by passing the products of combustion through water a precipitate of barium sulphate was obtainable upon the addition of barium chlorid. King[1] found an enormous increase in the solubility of sulphates upon heating in an oven at 110° C. using both gasoline and kerosene as a source of heat, thus largely eliminating this factor. In spite of the possibility of an introduction of error due to this cause it is probable that the results tabulated here disclose correctly the effect of heat upon the sulphates. In addition to the already-mentioned reasons, namely, destruction of organic matter, soil films, etc., it is necessary to take into consideration the chemical effect of heat upon the various mineral sulphur compounds. Calcium sulphate is known to exist in four forms, two being anhydrous, one of which is more soluble than the other. Sulphur also exists in soils as sulphids generally combined with iron, or as sulphates in combination with iron, lime, or magnesia, also combined with organic matter in many essential forms. The effect of heat would be most marked upon the latter in that it would undergo considerable decomposition at 250°, the sulphur being oxidized to sulphur dioxid or trioxid, which upon treatment with water as a solvent would tend to form sulphuric acid or sulphates to the extent of the bases in solution. On the other hand, it is evident that large amounts of sulphur will be lost through volatilization upon ignition. Soil No. 428, a highly organic soil, illustrates this effect best in that the increase from air dried to oven dried (100° C.) is 1,600 parts per million, while the decrease from the sample heated from 250° C. to ignition is 1,900 parts per million. It is evident from these data that upon igniting the soils the sulphur set free from the destruction of the organic matter is oxidized and volatilized so that it is lost before combination with the bases takes place.

BICARBONATES.

The following table shows the bicarbonate content of the water extracts:

Solubility of bicarbonates in water.

[Parts per million of dry soil.]

Treatment of soil.	Soil No. 74.	Soil No. 164.	Soil No. 9.	Soil No. 292.	Soil No. 290.	Soil No. 405.	Soil No. 416.	Soil No. 417.	Soil No. 406.	Soil No. 428.	Soil No. 426.
Air dried	370.1	106.4	113.5	158.5	132.9	161.4	35.4	73.6	52.5	73.1	70.5
Dried at 100° C.	448.0	137.4	419.4	283.7	202.7	297.5	221.4	286.0	136.4	204.3	102.7
Dried at 250° C.	1,309.2	91.3	338.9	363.5	327.7	157.3	153.3	143.0	68.2	582.8	895.4
Ignited	314.2	45.1	230.9	252.1	70.9	174.6	73.8	53.9	118.5	133.1	240.5

U. S. Dept. Agr., Bur. Soils Bul. 26 p. 56.

The results herewith shown are not very consistent, but the average indicates the maximum solubility of carbonic acid to be in the samples treated to 100° and 250° C., indicating that drying has the effect of increasing the amounts of bicarbonates in the soil and thus increasing the solubility of the bases with which carbonic acid combines. One reason suggested in the above table for a decrease in water soluble constituents upon ignition is that ignition would cause a transformation of the bicarbonates into normal carbonates, therefore temporarily reducing their solubility in water.

At the beginning of this work some determinations of titanium were made, but these were not carried through the series. This element was not present in the water extract in large enough quantities to be determined. In the dilute nitric acid extracts it was present in very small amounts in the samples dried in air and at 100° C., but in much larger quantities in the extracts from samples heated to 250° C. and ignition, the maximum solubility being obtained upon the ignited samples.

EFFECT OF HEAT UPON RICE AND TARO SOILS.

In the following table is shown the effect of heat upon the soils used in aquatic agriculture, comparing this with the solubility of the elements in the wet and soggy condition:

Effect of heat upon soils used in aquatic agriculture.

[Parts per million of dry soil water extract.]

Condition of sample.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxid (Fe_2O_3).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Phosphoric acid (P_2O_5).	Sulphuric acid (SO_3).	Bicarbonates (HCO_3).
Rice soil, No. 405:										
Wet	6.9	5.6	12.2	64.7	664.8	468.7	111.9	43.7	153.9	328.9
Air dry	2.3	7.6	6.4	5.9	296.9	209.7	96.6	27.1	129.6	161.4
Dried at 100° C.	6.9	13.8	9.2	10.3	133.3	130.9	55.1	31.0	149.3	297.5
Dried at 250° C.	5.7	17.6	5.4	14.9	363.0	151.6	45.9	33.0	942.0	157.3
Ignited	16.1	12.2	5.1	18.4	261.9	147.0	43.6	25.3	583.6	174.6
Taro soil, No. 406:										
Wet	36.6	62.4	86.1	34.4	318.6	310.0	31.8	38.7	137.8	294.9
Air dry	4.6	10.3	4.6	9.1	57.1	82.2	36.5	23.4	260.3	52.5
Dried at 100° C.	4.5	19.6	2.7	4.4	93.9	87.2	49.2	35.7	326.4	136.4
Dried at 250° C.	31.2	28.5	4.0	6.0	697.5	234.7	19.4	21.2	1,555.9	68.2
Ignited	33.5	38.0	2.1	9.6	547.7	245.9	78.2	23.4	1,479.9	118.5

When the types of soil were chosen for use in this series, two were selected with a view to obtaining some information upon the soils in use for rice and taro culture. It would be expected that heat and its accompanying oxidation would have a marked effect upon this type of soil for the reason that for the most part it exists in a reducing environment. The above table shows solubility in water only. The samples were taken from the field in wet condition and extractions were made upon weighed samples immediately upon receipt in the laboratory, the moisture content in this state being about

50 per cent. This table discloses the high concentration of soluble plant food in these soils under the reducing conditions. While the mineral constituents tend to increase in solubility with increase in heat with relation to the air-dry samples, a maximum solubility is obtained from the wet samples in the case of the iron, manganese, lime, magnesia, phosphoric acid, and bicarbonates, and in one of the samples a maximum solubility is obtained for the remaining constituents, silica, alumina, and potash. Therefore, these results indicate that the effect of drying and heating the soils used in aquatic agriculture does not increase the solubility of the mineral constituents over and above the solubility in the wet state but rather brings about a decrease in all constituents except sulphates.

The concentration of the extracts from these soils in the wet state does not necessarily indicate that the mineral constituents, with the exception of iron, are actually more soluble than those of dry-land soils. Neither should we conclude that the abnormal concentration is wholly due to more complete diffusion coupled with greater solubility induced by the environment to which these soils are subjected. The amount of water always present in these soils is far in excess of that occurring in dry-land soils, and since there necessarily must be a tendency toward constancy in concentration regardless of the amount of solvent present, in time the absolute amounts of solids going into solution would be considerably greater in submerged soils. The moisture content of these two soils when received at the laboratory was about 50 per cent, whereas the dry-land soils contain very much less moisture. The water extracts obtained by the methods employed, therefore, would necessarily contain greater absolute amounts of substances already in solution in the soil water. Hence the concentration of the nutrient solution occurring in submerged soils need not necessarily be greater than that of dry-land soils.

DISCUSSION.

The foregoing results show that an increase in solubility of the mineral constituents of various types of Hawaiian soils is effected by heating. The samples represent most of the normal and abnormal types of the islands. That there are both chemical and physical factors concerned in the phenomena at hand must be admitted at the outset. It is believed, however, that the most important set of factors affecting the solubility of inorganic soil constituents are of a physical nature.

Undoubtedly the means by which the physical factors act is through the soil moisture in its relation to the physical properties of the soil. The conditions conducive to the formation of a colloidal state and the subsequent relation of heat to the destruction of this colloid are two of the most important of these factors.

It is certain that soil moisture distributes itself around the soil particles and in some instances as an impregnation within the particles. The moisture therefore occurs as thin films which, according to certain physical conceptions, must be held around the particle by an enormous pressure. From purely physical considerations this pressure has been estimated at several thousand atmospheres. Under such pressure the concentration of film water with reference to the mineral matter should be much greater than that of the free or capillary water in the soil.

Then the air-dried soil, the particles of which are still surrounded by a film of moisture, when shaken with water, should theoretically show the least solubility. The results reported in this bulletin in most instances are in harmony with this assumption. But if the soil be allowed to remain in the condition and environment prevailing in submerged cultures, that is, in the presence of a large excess of water, then in time diffusion would bring about a more or less equal distribution of dissolved materials throughout the entire water present and the pressure of soil films would be decreased to a minimum or entirely eliminated. Hence the amount of materials going into solution in the free water in such soils would be expected to be abnormally high. Upon air drying such soils the normal films would again appear with a resulting decrease in solubility. Subsequent heating ought then to affect these soils in a way similar to that produced on dry-land soils. The data presented in the previous tables are again in harmony with this view.

Water, however, not only exercises a solvent action on minerals but forms various hydrates, the solubility and physical character of which in some instances are greatly altered; organic as well as inorganic matter goes into solution with the result that the moisture films around the particles became solution films, holding in suspension and more or less intermingled with colloids, both organic and inorganic. The films then may be looked upon as being of a colloidal nature.[1]

Upon heating to 100° C. alterations in the films would take place through evaporation and by partial dehydration of colloids, thus destroying the pressure by which the film was previously held around the particles. At the temperature of 100° C. the concentration of the soil moisture would also be temporarily increased, due to increase in solubility with heat. During the course of the evaporation the concentration of the soil moisture would increase to the saturation point, after which the mineral matter would be deposited on the surface of the film as evaporation went on.[2] Also the materials held in solution in the interior of the permeable particles would be partially deposited

[1] No claim is made for originality in this view. The idea of soil films, colloidal films, etc., has been made use of by various writers on soils.

[2] King (loc. cit.) in discussing the relative solubilities of fresh and dried soils advanced this idea.

on the surface of the water evaporated. Upon adding water to the soil after having been dried, it is probable the materials deposited from previous evaporation would be more soluble than the other mineral constituents. In addition a certain amount of oxidation and other chemical changes in the organic matter might reasonably be expected to take place, which would have some effect on the solubility of the mineral bases that tend to combine with the organic matter.

The solution obtained upon shaking with water a soil previously dried should, in the light of these views, be of a greater concentration than that prepared from the air-dried soil. With the absence of soil films and a more or less altered condition of the colloids present the solvent would have more ready access to the soil particles during a short period in addition to coming into immediate contact with solids deposited on the surface of the particles.

Why several of the mineral constituents of the soil should be so markedly more soluble when heated to 250° C. than at the other temperatures is a question not easily answered. The difference in physical effects were quite noticeable in that there was a greater aggregation of particles. Again, there was a more complete destruction of organic matter effected at this temperature, and also it is not entirely impossible that drying at 100° C. for eight hours does not effect a complete elimination of the soil moisture and especially the water of chemical combination. It seems reasonable, then, that the effects of heating to 100° C. are simply magnified when heated to 250° C. Added to this there is a more complete destruction of organic matter, the effect, both physical and chemical, being of the same general nature but more complete at the higher temperature. The destruction of organic constituents being more complete would necessarily increase the solubility of the mineral matter held in combination, as it is generally conceded that the organic constituents of the soil in its natural state are quite insoluble in water and acids, more especially in the former. There is also evidence of the existence of fatty or resinous organic matter which would materially affect the properties of the soil film. For the decomposition of such bodies it would be necessary to heat the soils considerably above 100° C.

In addition to the above-mentioned effects of heat the relation between solid and solvent would naturally be affected by other factors. Among these is the absorption or "fixing power" of the soil.[1] It is reasonable to expect soils with widely varying physical and chemical properties, such as those used in this series, to differ greatly in absorptive power. Hence it is not at all unlikely that the lack of consistency in some of the results in the foregoing tables is due primarily to this factor. Not only is there lack of uniformity in

[1] Richter (Landw. Vers. Stat., 47 (1896), p. 269) found that heating increased the absorptive power of the soil for water.

the absorptive power of soils, but they also show considerable selective power in the absorption of mineral constituents. Soils high in humus have a high fixing power, due to the ability of humus to combine chemically with minerals, as well as its power of absorption, and therefore the effect of heat upon highly organic soils should tend to increase the solubility of the minerals. An example of this is given in the cases of soils Nos. 74 and 428. Another factor is that of precipitation following extraction, being the more marked in the acid extract due to a more complete extraction.

In passing from 250° C. to ignition the effects are apparently of a specific rather than general nature, as has been already indicated. Among these effects are the volatilization of certain sulphur compounds, conversion of bicarbonates into normal carbonates, dehydration of silicates, etc., replacing of potash by lime, and other chemical transformations. In addition there is produced a greater aggregation of the soil particles, resulting in a decrease in surface area exposed to the solvent and an accompanying change in the fixing and absorbing powers of the soil. It is possible, by application of these conceptions, to explain the majority of changes, both increase and decrease in solubility, resulting from ignition.

THE EFFECTS OF HEAT ON SOIL NITROGEN.

INTRODUCTION.

The data presented in the preceding pages indicate the existence of colloidal films surrounding the soil particles. These films are probably both organic and inorganic in nature and undergo alteration under the influence of heat. By such alteration new surfaces become exposed to the action of solvents, thereby making possible the solution of materials otherwise effectively protected from the solvents used. There is considerable evidence in the data, however, that other changes were also produced by the heating. Some oxidations must have taken place, and probably decompositions of other types. Changes in the organic matter were produced at the higher temperatures, as shown by the color of the water extracts.

The effect of heat on soil organic matter has been the subject of some previous investigation. It has been observed, for example, that water extracts from heated soils are usually darker in color and contain greater amounts of organic matter than similar extracts from unheated soils.

Darbishire and Russell [1] found that plants absorb more nitrogen from soils that have been previously heated to 95° and 120° C. than from unheated soils. They concluded that the heating brought about some decompositions in the organic matter and also caused a modification in the bacterial flora.

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[1] Jour. Agr. Sci., 2 (1907), p. 305.

Pickering [1] found that partial sterilization brought about an increase in the solubility of the organic matter. An increase in the total nitrogen soluble in water and greater absorption of nitrogen by plants were also produced by heating.

Lyon and Bizzell [2] observed that the action of steam heat at 2 atmospheres pressure greatly increased the ammonia, in addition to increasing the water soluble inorganic matter. The nitrates were largely decomposed at this temperature and pressure.

Russell and Hutchinson [3] have shown that by heating some Rothamsted soils at 98° C. for three hours a small increase in the ammonia content took place. The most remarkable effect of the partial sterilization, however, was in connection with subsequent ammonification. Ammonia began to be formed in the course of a few days, followed by a remarkable production of ammonia later on. Corresponding to the increase in ammonia subsequent to heating, an enormous increase in the numbers of microorganisms (bacteria and fungi) took place. Heating to 125° also caused an initial production of small amounts of ammonia, but no subsequent ammonification set in. The nitrates were little affected although nitrification was entirely inhibited by the treatment. From the fact that volatile antiseptics bring about similar effects, these authors believe that partial sterilization kills certain biological agents which, in the untreated soil, effectively hold in check the multiplication and activity of the ammonifying organisms. After these inhibiting agents are destroyed the ammonifying efficiency of the soil rises rapidly, thus making available greatly increased amounts of nitrogen.

Lodge and Smith [4] found that decoctions from soils show an increase in ammonia after steam sterilization at 15 pounds pressure, but a decrease in ammonia took place from the sterilization of the subsoil.

Lathrop and Brown [5] found that the amounts of ammonia and total nitrogen soluble in water increased with an increase in the pressure under which the soil was heated. At 10 atmospheres approximately 40 per cent of the total nitrogen was rendered soluble, while the ammonia thus split off was found to vary from 7.83 per cent to 15.64 per cent.

Recently Schreiner and Lathrop [6] published a comprehensive investigation of the effects of steam heat on soil organic matter. In this work they isolated from heated soils a number of compounds not found in the unheated soil. Among the compounds isolated a

[1] Jour. Agr. Sci., 2 (1908), p. 411.
[2] New York Cornell Sta. Bul. 275 (1910).
[3] Jour. Agr. Sci., 3 (1909), pp. 111–144.
[4] Massachusetts Sta. Rpt. 1911, pt. 1, pp. 126–134.
[5] Jour. Indus. and Engin. Chem., 3 (1911), p. 657.
[6] U. S. Dept. Agr., Bur. Soils Bul. 89; Jour. Amer. Chem. Soc., 34 (1912), pp. 1242–1259.

number are nitrogenous and it is of special interest in this connection that practically all of these have been found to be beneficial to plant growth. Certain nonnitrogenous bodies, however, were also isolated, one of which, dihydroxystearic acid, seems to have been formed under the action of heat and which has been found to be distinctly toxic to plants.[1] It has been known for some time that steam heat may bring about toxic conditions in soils, apparently of an organic nature, but it remained for Schreiner and Lathrop to determine definitely what is at least one of the toxic bodies thus produced. On the one hand, these authors have shown that definite nitrogen compounds of a character beneficial to plant growth are formed by the action of heat, while on the other, a toxic compound, also organic and definite in character, may be generated at the same time. The significance of these discoveries is at once apparent; the value of such definite and fundamental data can not fail to be important.

A knowledge of the effects of steam heat on soil organic matter has special bearing on greenhouse practices, but may it not well be asked, what are the effects of dry heat without pressure? This phase of the question has not been exhaustively studied. It is unsafe to conclude a priori that the same types of cleavage and hydrolysis take place in the absence as under the influence of pressure. There is evidence in the growth and appearance of crops on burned soil that nitrogen is made available by the heat. The deep green color of the crop is sometimes very striking. It is important, therefore, that this phase of the question be investigated in a general study of soil heating on account of the importance of nitrogen in the nutrition of plants.

In an altogether different connection our attention was drawn to the very large increase in the ammonia of some Hawaiian soils brought about by the action of heat. It was observed that the ammonia content of certain soils increased from a few parts to over 400 parts per million. At the same time the nitrates were decomposed. From these observations and its general bearing on soil heating, an investigation of the nitrogen transformations seemed of interest and importance. Whence the ammonia thus set free and from what class of compound does it arise?

The nitrogen of soils having been at one time bound up in organized tissue, plant and animal, and, therefore, largely of proteid nature, undergoes hydrolysis under the action of enzyms, bacteria, etc., with the resulting formation or splitting off of simpler compounds. In soils there must occur every stage of these changes from the proteid complex, on the one hand, to inorganic compounds, on the other. The larger part of soil nitrogen exists, however, in complex organic combinations. Nevertheless, the simple inorganic nitrogen compounds,

[1] U. S. Dept. Agr., Bur. Soils Bul. 80 (1911).

especially nitrates, while occurring in relatively small amounts, have long been considered to be of great importance to plant growth.

For the purposes of this investigation two courses of procedure were open. First, a study of the changes that take place in the individual nitrogen compounds occurring in soils; second, a study of the group changes—that is, the effects of the treatment on the relative amounts and proportions of the large groups included under the amids, monamino acids, and diamino acids. The latter of these was chosen.

EFFECTS OF HEAT ON NITRATES.

The soils used in this investigation were taken from various localities in the islands and represent a wide range of types and conditions of formation. Some of the samples were taken from arid sections, some from intermediate, and still others from extremely humid sections. The method of heating differed somewhat from that employed in the work already reported. The time of heating was 2 hours, and the temperatures used were 100, 150, 200, 250° C. and steam heat in an autoclave at 2 atmospheres pressure. One hundred gram portions of air-dried soil placed in porcelain dishes were heated to the desired temperatures in an air bath, or autoclave. Nitrates were determined colorimetrically by use of the phenol disulphonic acid method, and ammonia, from separate portions, by distillation with magnesium oxid in the usual way. It should be remembered that the ammonia thus obtained probably occurred in part as amids. Distillation with magnesium oxid is known to liberate ammonia from amids. In a few instances the modified method of Schloesing,[1] which consists in leaching the soil with dilute hydrochloric acid and then distilling the ammonia from the filtrate with the use of magnesium oxid, was employed. The results were very similar to those obtained by direct distillation. The following table shows the effects of heat on the nitrate content:

The effects of heat on soil nitrates.

[Nitrate nitrogen expressed in parts per million of air-dried soil.]

Temperature.	Soil No. 9.	Soil No. 290.	Soil No. 292.	Soil No. 329.	Soil No. 335.	Soil No. 407.	Soil No. 411.	Soil No. 428.
Unheated	108.0	18.0	17.6	197.0	3.3	0.7	56.0	70.0
100° C.	95.0	18.6	13.0	158.0	2.0	.7	60.0	70.0
150° C.	57.0	12.5	23.5	61.5	3.0	.6	1.7	49.5
200° C.	5.0	6.5	3.5	1.3	.6	.5	1.5	.8
250° C.	5.4	.5	1.4	3.5	1.0	.4	.5	.5
Steam pressure 2 atmospheres	94.0	10.5	12.5	148.0	1.0	.6	48.0	46.0

These data are of interest as showing the destructive effect of heat on soil nitrates. In most instances the nitrates underwent considera-

[1] Referred to by Jodidi, Michigan Sta. Tech. Bul. 4, p. 11.

ble decomposition at 150° C., while at 200 and 250° C. practically total decomposition took place. Heating to 100° C. had but little effect. Steam heat at 2 atmospheres pressure brought about somewhat less decomposition than dry heat at 150° C.

EFFECTS OF HEAT ON THE AMMONIA CONTENT.

In the next table will be found the data showing the effects of heat on the ammonia content.

Effects of heat on the ammonia content of soils.

[Ammonia nitrogen expressed in parts per million of air-dried soil.]

Temperature.	Soil No. 9.	Soil No. 290.	Soil No. 292.	Soil No. 329.	Soil No. 335.	Soil No. 407.	Soil No. 411.	Soil No. 428.
Unheated	28.0	18.1	11.2	56.0	12.6	9.1	19.6	63.7
00° C	23.8	19.6	10.5	64.4	18.2	13.5	28.0	72.8
150° C	67.2	45.2	32.2	81.6	17.5	28.7	77.7	127.2
200° C	187.6	464.8	174.3	218.4	32.2	368.2	170.8	274.4
250° C	40.6	206.5	336.0	28.0	19.6	114.8	98.0	238.0
Steam pressure, 2 atmospheres	83.3	51.1	16.8	77.7	16.1	46.2	69.2	112.7

The ammonia content of soils Nos. 329 and 428 before heating is here shown to be abnormally high. Generally soils contain ammonia to the extent of a few parts per million only, whereas the nitrate content may rise to considerable concentration.[1]

Under the influence of heat the ammonia content of all the soils studied was greatly increased, practically reaching a maximum at about 200° C. Above this temperature a falling off took place which was probably due to a loss of ammonia through volatilization. We here have, therefore, some interesting and, as seems probable, very important facts. As pointed out above, heat considerably increases the solubility of the inorganic matter. Here it is shown that the ammonia content is enormously increased also.

Formerly little attention was given to the ammonia content of soils except in its relation to nitrification. During the past few years, however, the idea that ammonia may serve as a direct source of nitrogen to higher plants has steadily gained ground. It is now known that certain aquatic plants, rice in particular, not only can utilize ammonium nitrogen but that this form of nitrogen is better adapted to assimilation by rice [2] than is nitrate. Other crops [3] have also been found to be able to transform ammonia into proteids with

[1] Ammonia in soils, produced by biological agents, has for some time been looked upon as being merely a transitional state, its formation being essential to nitrification. The nitrifying organisms seize on the ammonia and convert it into nitrites and then into nitrates, thus effectively preventing an accumulation of ammonia in the soil at any one time. One of the essentials of vigorous nitrification, however, is free oxygen, while ammonification may take the place under anaerobic conditions. In many Hawaiian soils aeration is very low, and for this reason (perhaps others), nitrification frequently does not keep pace with ammonification.

[2] See Hawaiian Sta. Bul. 24.

[3] Krüger, Landw. Jahrb., 34 (1905), No. 5, p. 761.

equal facility. From the large number of cultures that have been reported and the many observations made it is safe to assume that the ammonia of natural soils is absorbed and assimilated to a greater or less extent by nearly all plants. We may conclude, therefore, that an important part of the action of heat on soils has to do with the production of ammonia.

As previously stated, Schreiner and Lathrop (page 29) have shown that the major portion of the organic nitrogen compounds, split off from more complex bodies in soils under the action of heat, is also beneficial to plant growth. With the additional production of relatively large amounts of ammonia it is probable that marked stimulation would result.

The effect of heat viewed from this standpoint is also of interest in its relation to the effects of partial sterilization. As already stated, one of the pronounced effects of partial sterilization, either with heat or volatile antiseptics, is the abnormal ammonification thus induced and which seems to be correlated with marked plant stimulation. In some Hawaiian soils the effect of partial sterilization on subsequent ammonification has recently been found to be exceptionally great. If the accumulation of ammonia as a result of partial sterilization reacts beneficially on plants, we certainly have a right to conclude that its direct production by means of heat would also prove stimulative to crops.

EFFECTS OF BRUSH BURNING IN THE FIELD.

With the view to determining the effects produced by burning refuse, brush, etc., in the field, a few samples of soil from spots where brush had been burned were examined at two different times. The brush was burned about September 1 and the samples were taken September 10 and November 7, respectively. Care was taken to remove the ashes so as to secure portions of the uncontaminated soil. Samples of unburned soil near by were taken at the same time. Ammonia and nitrates were determined in the samples as follows:

Effects of burning brush on soil nitrogen.

[Parts per million of nitrogen in air-dried soil.]

Laboratory No.	As nitrates.		As ammonia.	
	After 10 days.	Two months later.	After 10 days.	Two months later.
402 (burned)	6.5	5.5	50.4	100.8
402a (not burned)	20.0	18.0	39.2	70.0
403 (burned)	6.0	8.0	161.0	106.4
403a (not burned)	6.0	8.0	21.0	32.2
404 (burned)	16.0	22.0	77.0	114.8
404a (not burned)	52.0	52.0	8.4	30.8

Here again it is shown that an increase in the ammonia and a decrease in nitrates takes place in soil heating. The content of ammonia and nitrates at the end of two months is of special interest. The above data show that not only is ammonia formed by the action of heat but that subsequently ammonification took place at a greater rate in two cases out of three than in the unburned soils. Nitrification, however, was not restored under the existing field conditions. It is probable that reinoculation with both the ammonifying and nitrifying organisms gradually took place, but the lack of aeration prevented the development of the nitrifying bacteria. These soils had not been cultivated for two years previously and received no tillage during the time of observation. It is not possible to state the temperature to which the soil was heated in these instances. An approximate test applied in another locality, however, indicates that the burning of small brush heaps similar to those burned on the soils above discussed created a temperature of about 200° C. 6 inches below the surface. The temperature would naturally vary greatly from place to place.

EFFECTS OF HEAT ON THE ORGANIC NITROGEN.

Having found that large amounts of ammonia are formed from the action of heat, a study of the organic nitrogen as affected by heat seemed of interest. It is well known that ammonia is one of the cleavage products of protein hydrolysis. It is also known that in the destructive distillation of organic nitrogenous substances ammonia is one of the decomposition products. It was observed that the amounts of ammonia recovered from heated soils by means of distillation were not proportional to the total nitrogen present, but seemed to depend largely on the type of the soil. The amount of ammonia obtained, for example, from soil No. 335 was very much less than that from the other samples studied (page 32). Ammonia, therefore, was probably volatilized and driven out of the soil to a greater extent in some instances than in others. Soil 335 is a sandy soil composed very largely of coral sand ($CaCO_3$). In the foregoing work total nitrogen determinations were not made. Hence it is impossible to correlate the rise and fall of ammonia with losses of nitrogen.

In order to throw further light on these questions total nitrogen and the several groups of nitrogen compounds rendered soluble in boiling hydrochloric acid were studied. For this purpose the method of Hausmann[1] as modified by Osborne and Harris[2] was applied. This method was devised for a study of protein chemistry, but has been previously used by Jodidi and others in studying the organic nitrogen of soils.[3]

Ztschr. Physiol. Chem., 27 (1899), p. 95. Jour. Amer. Chem. Soc., 25 [illegible], p. 323.
Michigan Sta. Tech. Bul., 4 (1909); Iowa Sta. Research Bul., 1 (1911).

In this study total nitrogen, nitrates, ammonia, amids, diamino acids, and monamino acids were determined. Nitrates and ammonia were determined in the soil directly, while the groups of organic compounds were determined in solutions obtained by boiling 50 grams of soil with 750 cubic centimeters of hydrochloric acid under a reflux condenser for 10 hours, as outlined by Jodidi, filtering, and making the filtrate up to 1 liter.

The organic nitrogen of soils, having at one time been bound up largely in proteid combinations, may reasonably be expected to yield hydrolytic products similar to those formed from protein. But little is known, however, regarding the specific hydrolysis induced by the microflora of the soil. It is not known, for example, whether the protein molecule as a whole is broken down with the ultimate liberation of ammonia from the several classes of protein cleavage products in the same ratio in which nitrogen occurs in them or whether certain of these groups yield inorganic or elementary nitrogen more readily than others.

Samples of both heated and unheated soil were studied in this connection. The former were subjected to a temperature of 200° C. for a period of two hours, after which the same treatment and determinations were made as in the unheated portions. The results are recorded in the following table:

Nitrogen compounds in heated and unheated soils.

Soil numbers.	Total nitrogen.	Nitrates.	Ammonia.	Soluble in hydrochloric acid.					Composition of hydrochloric acid soluble.			
				Amids.	Diamino acids.	Monamino acids.	Total.	Per cent of total.	Ammonia.	Amids.	Diamino acids.	Monamino acids.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Unheated:												
379	0.546	0.001	0.001	0.096	0.030	0.298	0.426	78.02	0.23	22.53	7.04	69.95
405	.179	.0001	.005	.042	.018	.100	.165	92.18	3.03	25.45	10.91	66.66
406	.504	.0015	.006	.079	.055	.240	.381	75.59	1.57	20.74	14.43	62.97
428	.779	.0045	.022	.129	.029	.363	.558	71.63	3.94	23.12	5.9	65.05
447	.396	.0062	.001	.074	.033	.125	.239	60.35	.41	30.69	13.80	52.30
Heated:												
379	.417	.0	.069	.098	.034	.168	.369	88.49	18.69	26.56	9.20	45.53
405	.178	.0	.036	.055	.017	.044	.152	85.39	23.68	36.18	11.18	28.95
406	.419	.0	.067	.103	.019	.092	.281	67.05	23.84	36.65	6.76	32.74
428	.608	.0	.031	.077	023	.079	.210	34.54	14.76	36.66	10.95	37.62
447	.207	.0	.020	.039	.022	.028	.109	52.65	18.35	35.78	20.18	25.69

Considering first the unheated soils, the nitrates and ammonia are shown to constitute a relatively small percentage of the total nitrogen and to vary greatly in the different soils examined. Soil 447 was found to contain the highest amount of nitrates, while in No. 405 nitrates were present to the extent of only one part per million. No. 428 contained an abnormally high ammonia content,

while Nos. 405 and 406 also contained many times as much ammonia as nitrates.

The relative amounts of nitrogen extracted by hydrochloric acid also varied greatly. In soil No. 405, 92.18 per cent of the total nitrogen went into solution, while No. 447 yielded only 60.35 per cent of its nitrogen. Nos. 405 and 406 are soils that have been devoted to aquatic agriculture (rice and taro) for many years, while soils 379, 428, and 447 have been subjected to dry-land cultures.

The chemical decompositions and hydrolyses that take place naturally in the organic matter of soils being brought about largely by biological agents, it is probable that the range and types of such reactions in submerged soils are somewhat different from those taking place in well-aerated soils. There are several lines of reasoning not necessary to mention here that lead to this conclusion. From this point of view, then, the biological effects on soil nitrogen may reasonably be expected to be different in the two instances. The nature of the organic matter originally incorporated with the soil probably has some bearing on this question also.

Among the several groups of nitrogen compounds brought into solution by hydrochloric acid it is noteworthy that the amids and monamino acids constitute the main portion. The latter comprises approximately two-thirds of the total nitrogen dissolved. It should be borne in mind, however, that the monamino nitrogen was determined by difference; that is, by subtracting the sum of the other groups from the total nitrogen in solution. It is known, however, that this difference is not made up entirely of monamino acids. Jodidi[1] found, for example, that the monamino nitrogen group in Iowa soils was made up of from 40.12 to 92.11 per cent of actual monamino acids, the variation in this respect being dependent in part on the treatment to which the soil had been previously subjected. It is of interest that the relative amounts of amids, monamino, and diamino nitrogen in Hawaiian soils were found similar to those of soils elsewhere.

Turning now to the question of heat as affecting soil nitrogen, it was found that with the exception of No. 405 the average loss of nitrogen was about 25 per cent, but in certain soils the loss was much greater than in others. Soil No. 447 suffered a loss of practically 50 per cent while No. 405 sustained almost no loss of nitrogen. It is also of interest that the reduction in the amounts of nitrogen extracted by hydrochloric acid was greater in two instances and less in three than the absolute loss of nitrogen occasioned by heat. In every instance enormous increases in ammonia and a total decomposition of nitrates took place. On the whole, the absolute amounts of neither the amids nor the diamino acids were greatly affected by

[1] Iowa Sta. Research Bul. 1 (1911).

heat, whereas there was relatively large reduction in the nitrogen of the monamino acid group in every soil studied.

Heating, therefore, caused a loss of nitrogen on the one hand and an increase in ammonia on the other, and the decompositions appear to come principally from the monamino acid group. The amounts of amids in soils Nos. 428 and 447 and the diamino acids in Nos. 406 and 447 also sustained considerable loss from the heating.

Regarding that portion of soil nitrogen remaining insoluble in hydrochloric acid, next to nothing is known. By again referring to the table (p. 35) it will be seen, however, that the heat had some effect on the insoluble nitrogen compounds. The difference between the total nitrogen in the soil and that extracted shows that considerable reduction in the insoluble nitrogen of soils Nos. 379 and 447 took place by heating, while there was a gain in the insoluble nitrogen of soil No. 428. The organic matter of soil No. 428 is in a less advanced stage of decomposition than that of the other soils studied and it was noticed that a pronounced charring in this soil took place under the action of the heat. It seems probable that such charring of the organic matter would tend to protect the nitrogen bodies in the interior of the particles from the action of the solvent, thus apparently increasing the percentage of insoluble nitrogen.

SUMMARY.

(1) Twelve different soils representing a wide range of types and agricultural conditions were studied with reference to the effects of heating to 100° C., to 250° C., and to ignition. The solubility of all the mineral constituents except sodium was determined, using water and fifth-normal nitric acid as solvents. The effects on the nitrogen compounds were also investigated.

(2) The results showed considerable variation. Neither the absolute nor the relative solubility of the inorganic constituents were effected similarly in all the samples studied.

(3) On the average, drying at 100° C. was found to bring about an increase in the water soluble manganese, lime, magnesia, phosphoric acid, sulphates, and bicarbonates. At this temperature an increase in the solubility of potash, silica, and alumina was produced in about 50 per cent of the soils examined, but a decrease was observed in the solubility of these elements in some instances. The solubility of iron was decreased in most instances.

(4) Heating to 250° C. or ignition produced effects on the solubility in water similar to those brought about at 100° C., but varying in degree, these being sometimes greater, sometimes less in intensity than those produced at 100° C.

(5) The solubility in fifth-normal nitric acid was not greatly affected by heating to 100° C., but in some instances heating to

250° C. considerably increased the solubility of alumina, manganese, potash, and phosphoric acid and at the same time effected a reduction in the solubility of lime and magnesia. Upon ignition the solubility of silica, alumina, potash, phosphoric acid, and sulphates was increased, while the solubility of lime and magnesia underwent a corresponding decrease.

(6) The solubility of soils used in aquatic agriculture is abnormally high, but upon drying out these become much less soluble and approach a state similar to that existing in aerated soils. When such soils are heated after drying they seem to undergo changes of the same order as are produced in dry-land soils.

(7) No single factor is sufficient to cover the solubility effects resulting from heating Hawaiian soil. On the other hand, the subject is very complex and involves many factors. Among the more important of these may be mentioned flocculation, deoxidation of manganese dioxid, oxidation, particularly of iron, double decomposition, dehydration, and the attending physical alterations of soil films. Such alteration would destroy film pressure, thus allowing the solvent to come into more intimate contact with the soil constituents. At the higher temperatures bicarbonates become converted into normal carbonates, thus effectively lowering the solubility of lime and magnesia.

(8) Nitrates undergo decomposition with heat, a decrease in nitrate content having been found to take place at 150° C., while at 200° or 250° C. practically total destruction of nitrates took place.

(9) One of the noteworthy effects of soil heating is the production of ammonia, which at 200° C. was formed in abnormally large amounts. Soil subjected to heat from brush burned in the field was found to undergo stimulated ammonification after heating. Nitrification, on the other hand, was not restored after the lapse of two months.

(10) Heating to 200° C. caused a loss of approximately 25 per cent of the total nitrogen. A loss of nitrogen and the ammonia formed by the action of heat came largely from the monamino acid group, while the amids and diamino acid sustained much less loss.

(11) The results of these studies are believed to throw important light on the subject of soil aeration and consequently have a direct bearing on the practical question of soil management.

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Issued January 17, 1914.

HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 31.

RICE SOILS OF HAWAII:

THEIR FERTILIZATION AND MANAGEMENT.

BY

W. P. KELLEY,

CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1914.

HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *October 1, 1913.*

SIR: I have the honor to submit herewith and recommend for publication, as Bulletin No. 31 of the Hawaii Agricultural Experiment Station, a paper on Rice Soils of Hawaii: Their Fertilization and Management, by W. P. Kelley, chemist. The experiments on rice as carried out by this station indicate quite conclusively that for the most successful production of rice all conditions which tend toward nitrification should be avoided. The application of nitrates has been found to be of little or no avail, and sometimes even positively injurious, while the use of ammonium sulphate brings about greatly increased yields. In harmony with this finding is the evidence that conditions which allow nitrification to take place in rice soils result in a diminished yield of rice. It appears, therefore, that ammonium sulphate should be the form of commercial nitrogen to apply to rice and that rice soils should not be aerated between crops. These results are probably applicable to other regions than the rice lands of Hawaii.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

RICE SOILS OF HAWAII: THEIR FERTILIZATION AND MANAGEMENT.

INTRODUCTION.

The extensive soil investigations that have been made up to the present time have dealt principally with dry lands, in which the moisture and other conditions differ greatly from those prevailing in rice soils. In America in particular very little study has been devoted to submerged lands, and little, indeed, is really known about them. Consequently recommendations for the treatment and management of rice soils are generally based on knowledge gained from experience with dry lands. It is evident, however, that conclusions applicable to dry soils do not necessarily apply to submerged soils such as are used in rice culture, and, in fact, it is well known in oriental countries that rice lands demand different treatment from those devoted to dry-land cultures.

The one condition that is most obviously different in rice soils and dry lands is that of aeration. The fact that aeration is essential to the successful growth of most crops, and the belief that fertility is in some way dependent upon its maintenance, has caused agriculturists to recommend for rice soils practices designed to secure aeration in the belief that this is as essential for successful rice culture as for culture of other crops. Experiments are not wanting, however, which show this to be untrue.

One of the most important matters affecting the culture of rice is the form in which nitrogen is taken up by the crop. It is well known that the degree of aeration in soils determines very largely the form assumed by available nitrogen. This phase of the subject has been reported upon previously by the writer,[1] but will be further emphasized in this bulletin on account of the principle involved and the practical importance attached to it.

In connection with the general soil investigations, which have been under way in the laboratory of the Hawaii station for several years, the rice lands of the Hawaiian Islands have received considerable attention. For a number of years also field experiments with different

[1] Hawaii Sta. Bul. 24.

fertilizers for rice have been conducted by the station. The subject has been approached from a number of standpoints, both practical and scientific, and it is believed the results are of sufficient interest and value to warrant publication at this time.

ORIGIN OF RICE SOILS.

The rice soils of Hawaii are located at or near sea level along the coast and are not extensive in area, amounting to about 10,000 acres, and during recent years the tendency has been to plant other crops on some of the lands hitherto devoted to rice because of low yields, labor difficulties, etc. The extent of the industry, therefore, is on the decline. The soils have their primary origin in basaltic lavas, just as is the case with all the soils of the islands, but in addition they frequently contain varying amounts of coral lime ($CaCO_3$), which has become thoroughly mixed with the lava residues. Whether or not the coral is visible on the surface, in practically all cases the rice lands are underlain at various depths with deep beds of coral limestone. Notwithstanding the fact that the lavas are typical basalts, the chemical and physical properties vary enormously; moreover, the rates of disintegration and the composition of the residuum differ greatly from place to place. Therefore the soils coming from lavas of essentially the same type may be very different in composition and properties. The low lands in and around Honolulu, for instance, having been derived from the disintegration of volcanic cinder, typical black sands, are widely different from the rice lands on the leeward side of Oahu, both in chemical and physical properties. This is especially noticeable in the relative percentages of lime and magnesia.

In most instances the rice soils are strictly alluvial, although on account of the close proximity of the mountains there has been but a limited transportation of the soil materials. The soils in places contain a high percentage of organic matter.

In certain localities, as, for instance, the Hanalei Valley, on Kauai, the soils contain high percentages of clay and are of a close texture. The rice lands around Honolulu, on the other hand, contain quantities of sand and gravel unusual for Hawaiian soils, and as a consequence are open and porous. Samples of soil from all the important rice sections have been examined.

MECHANICAL COMPOSITION.

In view of its bearing on irrigation, etc., the mechanical composition as shown by physical analysis has been determined and is recorded in the following on page 5.

Physical analyses of rice soils.

District.	Fine gravel, 2–1 mm.	Coarse sand, 1–0.2 mm.	Fine sand 0.2–0.04 mm.	Silt, 0.04–0.01 mm.	Fine silt, 0.01–0.002 mm.	Clay, 0.002 mm. or less.	Organic matter and combined water.
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	20.91	18.75	22.04	8.69	12.41	7.23	8.71
Subsoil 293	18.61	18.30	22.74	8.10	13.48	9.52	10.77
Fort Shafter:							
Soil 332	1.15	1.61	18.34	16.28	23.88	25.39	14.37
Subsoil 333	1.02	1.28	20.63	17.88	22.11	24.06	14.05
Soil 334	.62	1.63	15.33	15.77	21.73	31.61	15.23
Kailua:							
Soil 337	.35	.69	18.78	13.57	22.92	25.70	18.72
Subsoil 338	.33	.86	18.60	15.97	21.97	23.97	19.54
Soil 339	.13	.22	18.13	20.42	22.37	19.19	21.17
Subsoil 340	.06	.31	16.75	19.27	23.42	22.98	19.41
Kaneohe:							
Soil 343	.05	.19	16.03	30.79	14.64	20.16	15.44
Subsoil 344	.22	.11	15.29	28.94	20.67	21.73	13.20
Waiahole:							
Soil 345	.15	3.09	25.94	20.97	15.96	19.84	15.04
Subsoil 346	.46	3.59	34.44	19.30	10.96	14.29	15.31
Kalaunui:							
Soil 347	.41	.83	21.49	27.45	7.61	6.38	36.14
Subsoil 348	.22	.64	11.29	15.27	20.07	6.19	49.24

The above data show that the rice soils of Oahu, with the exception of those from the Waikiki and Kalaunui districts, are very similar in mechanical composition, and are made up of approximately equal quantities of fine sand, silt, fine silt, and clay. The Waikiki soils, on the other hand, contain relatively small amounts of clay, with correspondingly larger amounts of the coarser grained particles. None of the soils except from this district contains any material coarser than fine gravel, while that from Waikiki contains several per cent of stones, etc. This point is of importance because of its bearing on tillage and drainage. The soils from Kalaunui, on the other hand, are very highly organic, and in places this land is peaty to a considerable degree. The organic matter of this soil, however, retards the passage of water through it, with the result that the amounts of water used in its irrigation are practically normal for the islands.

In the main these soils are to be classified as clay loams with a rather high organic content. The irrigation of all these soils requires relatively large amounts of water on account of their porous nature.

In considering the mechanical composition of Hawaiian soils it should be especially borne in mind that the terms clay, fine silt, etc., have reference only to the size of the particles, and that these are made up of different chemical substances from those that go to make up clay in most continental soils. Furthermore, the properties of so-called clay in Hawaiian soils differ from the properties of other clays. It is not composed primarily of kaolin, but is made up of ferric and aluminum hydrates, together with double silicates of iron and aluminum and perhaps some aluminum silicate. In

addition the coarser particles are in the main merely lava fragments on their way toward more complete disintegration. These frequently show under the microscope the characteristic structure of lava. As time goes on the relative proportions of these constituents will change, so that eventually a higher percentage of clay and fine silt will predominate. The upland soils at the present time frequently contain practically no material coarser than silt, with abnormally large quantities of clay. The soils are typical laterites,[1] and in interpreting the analytical results reported herein it is important to bear this in mind.

CHEMICAL COMPOSITION.

The chemical composition of these soils, as determined by the use of the official methods, is shown in the following table:

Chemical composition of rice soils.

District.	Insoluble matter.	Potash (K_2O).	Soda (Na_2O).	Lime (CaO).	Magnesia (MgO).	Manganese oxid (Mn_3O_4).	Ferric oxid (F_2O_3).
OAHU.							
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	41.69	0.42	1.47	1.99	9.42	0.27	18.01
Subsoil 293	38.82	.47	1.36	2.48	9.75	.21	21.22
Fort Shafter:							
Soil 332	44.57	.25	.46	.97	.94	.32	18.84
Subsoil 333	45.75	.26	.36	.87	.58	.30	18.48
Soil 334	44.94	.27	.34	.81	.99	.13	17.56
Kailua:							
Soil 337	40.53	.26	.45	.76	.82	.09	19.01
Subsoil 338	42.60	.16	.46	.59	.49	.27	19.67
Soil 339	37.20	.14	.44	.43	.26	.08	24.80
Subsoil 340	38.20	.06	.37	.47	.31	.11	26.15
Kaneohe:							
Soil 343	50.10	.10	.36	1.22	.87	.51	11.20
Subsoil 344	51.15	.15	.38	1.65	.73	.52	10.50
Waiahole:							
Soil 345	50.52	.09	.24	1.20	1.08	.42	17.25
Subsoil 346	48.30	.08	.28	1.63	1.54	.45	16.18
Kalaunui:							
Soil 347	37.82	.12	.31	2.20	.79	.32	7.05
Subsoil 348	27.70	.09	.32	2.76	.78	.35	6.44
KAUAI.							
Hanalei Valley:							
Soil 460	42.40	.16	.10	1.16	2.67	.09	16.22
Soil 461	40.40	.27	.10	.97	3.35	1.16	17.10
Soil 462	47.25	.19	.41	1.18	2.28	.02	14.82
Soil 463	47.00	.17	.34	.97	6.98	.04	18.20
Soil 464	45.18	.15	.42	1.26	1.72	.14	15.32
Soil 465	45.70	.14	.45	1.38	2.65	.23	15.23
Soil 466	45.35	.15	.29	.96	4.16	.15	18.16
Soil 467	43.30	.17	.31	1.16	3.07	.13	15.91

[1] The decomposition of basaltic lavas usually gives rise to soils high in iron and aluminum and relatively low in silica, and while the most finely divided particles are usually referred to as clay, the name is improperly applied. Recently Ulpiani (Staz. Sper. Agr. Ital., 45 (1912) pp. 629–653) suggested that this process be called lateritization in contradistinction to kaolinization, which takes place in the decomposition of orthoclase feldspars.

Chemical composition of rice soils—Continued.

District.	Alumina (Al_2O_3).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Titanic dioxid (TiO_2).	Loss on ignition.	Total.	Nitrogen (N).
OAHU.							
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	14.10	0.62	0.08	2.17	9.10	99.34	0.16
Subsoil 293	13.09	.71	.11	2.64	9.92	100.78	.16
Fort Shafter:							
Soil 332	17.10	.32	.03	2.26	13.96	100.02	.16
Subsoil 333	17.42	.26	.10	2.17	13.58	100.13	.13
Soil 334	19.35	.45	.23	1.53	13.70	100.32	.23
Kailua:							
Soil 337	14.94	.76	.26	2.43	18.63	98.94	.44
Subsoil 338	14.50	.68	.26	2.13	18.43	100.24	.42
Soil 339	12.72	.29	.20	2.92	21.10	100.58	.41
Subsoil 340	12.45	.22	.20	2.81	18.41	99.76	.30
Kaneohe:							
Soil 343	20.35	.20	.04	2.24	13.85	100.94	.20
Subsoil 344	20.90	.23	.04	2.37	12.30	100.92	.17
Waiahole:							
Soil 345	14.92	.21	.20	1.64	13.22	100.99	.21
Subsoil 346	15.30	.23	.13	1.60	14.70	100.42	.20
Kalaunui:							
Soil 347	14.40	.19	.31	2.28	34.52	100.31	1.24
Subsoil 348	12.42	.13	.80	1.90	46.70	100.39	1.44
KAUAI.							
Hanalei Valley:							
Soil 460	20.15	.44	.27	2.78	14.15	100.59	.26
Soil 461	20.10	.52	.28	3.00	14.35	101.60	.24
Soil 462	19.12	.53	.35	2.67	12.25	101.07	.20
Soil 463	13.60	.35	.30	2.06	10.42	100.43	.18
Soil 464	20.30	.51	.28	2.93	12.95	101.17	.20
Soil 465	19.95	.72	.31	2.27	11.27	100.30	.15
Soil 466	16.95	.31	.26	2.57	11.80	101.10	.17
Soil 467	20.35	.56	.31	2.70	13.35	101.35	.17

It will at once be seen that these soils differ from normal soils not only in physical properties but also in chemical composition.

The lavas from which these soils have been derived are made up primarily of pyroxenes or amphiboles and soda-lime feldspars, and therefore are characteristically basic. In the disintegration process solution and oxidation play the most important parts, with the result that the soils formed contain iron and aluminum in great quantities, while the potash, soda, lime, and magnesia are largely leached out as silicates. In a few instances the rice soils, however, contain relatively large amounts of lime and magnesia, due partly to admixtures with coral limestone and in part to the type of lava from which they were derived. It is also noteworthy that the ratio of lime to magnesia in these soils is abnormal, the latter sometimes being present in great excess above the former. In view of the interest now taken in the lime-magnesia ratio the relations of these two elements are of special interest, particularly since rice has been extensively studied in connection with this ratio.

The potash content is rather low, while phosphoric acid is generally present in large amounts. From a superficial examination of these analyses it would seem that potash fertilization is needed. It will be shown in connection with the fertilization studies, however, that there

is no need for potash fertilizer. The decomposition of the lava fragments is greatly increased by the products arising from the decay of organic matter under the prevailing anaerobic conditions, with the result that potash is rendered soluble at a rate sufficient to supply the needs of rice, but the limited supply of potash present, together with the fact that large amounts of potash are taken up by rice, will sooner or later necessitate the use of potash-bearing fertilizer.

FERTILIZER EXPERIMENTS.

Some fertilizer experiments with rice have already been published by this station.[1] The results were such as to emphasize the need for a more systematic study of this question, and in view of the fact that the yields obtained by the rice growers throughout the islands are frequently unprofitable, a series of fertilizer tests were instituted on the rice trial grounds of the station in the spring of 1909. These experiments were continued on the same plats throughout seven consecutive crops. In Hawaii little or no rotation of crops is practiced, and two crops of rice are grown on the same land each year.

The soil on which these experiments were made had been previously devoted to rice culture and was known to be quite uniform in productivity. After the plats had been laid out, however, an additional crop, without fertilization, was grown for the purpose of determining more definitely their uniformity. The results showed the plats to be extremely uniform throughout, practically the same yield having been obtained from each. The plats were separated by low dikes so constructed as to prevent the lateral movement of fertilizers and irrigation was adjusted so as to insure a constant water supply of about 2 inches in depth above the surface of the soil.

After harvesting the first crop the original plats were divided into two equal portions, which here are to be designated as series A and B. The former were fertilized previous to the time of transplanting the spring crop only, while the latter received the same applications in like quantities to both the spring and fall crops. Previous experience had suggested that nitrogen would prove to be the most needed element, and this was borne out by the results obtained later. The yields obtained, fertilizers applied, etc., are recorded in the tables, using the following values in calculating the cost of fertilizers, profits, etc.: Ammonium sulphate, \$80 per ton; superphosphate, \$20 per ton; potassium sulphate, \$55 per ton; paddy, \$0.025 per pound. In calculating the profit or loss, the extra expense incurred from the increased labor attached to making the application of fertilizers, harvesting, and marketing the increased yields, etc., was not included.

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[1] Hawaii Sta. Rpts. 1907 and 1908.

Results of applying fertilizers to spring crop only.

1909—SERIES A.

Plat.	Fertilizer.	Yield per acre.						Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.	Increase in paddy per annum.		
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	1,950	[1] 1,950	6,662	....	....	....
2	Superphosphate, 225 pounds; Potassium sulphate, 120 pounds	1,641	1,625	2,242	3,250	8,758	9	$5.55	−$5.33
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,667	2,632	9,028	0	9.30	− 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	2,275	3,217	9,732	479	8.25	+ 3.72
5	None	1,267	1,543	2,275	3,347	8,432	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	2,925	3,347	10,464	723	11.55	+ 6.52
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	2,250	3,152	11,121	1,243	23.10	+ 7.96
8	Ammonium sulphate, 300 pounds	2,405	2,730	2,307	3,315	10,757	1,179	12.00	+17.47
9	Ammonium sulphate, 150 pounds	1,950	2,285	2,502	3,867	10,604	1,286	6.00	+26.15
10	None	1,379	1,528	2,372	3,315	8,594	....	....	....

1910—SERIES A.

Plat.	Fertilizer.	Spring crop Straw.	Spring crop Paddy.	Fall crop Straw.	Fall crop Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,657	1,527	1,560	[1] 1,202	5,946	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,690	1,722	1,852	2,015	7,279	0	$5.55	−$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,950	1,722	1,560	1,852	7,084	0	9.30	− 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,982	2,047	1,820	2,080	7,929	65	8.25	− 6.63
5	None	1,690	1,885	1,755	2,177	7,507	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,917	2,307	1,755	2,307	8,286	552	11.55	+ 2.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,470	3,055	1,820	2,210	9,555	1,203	23.10	+ 6.97
8	Ammonium sulphate, 300 pounds	2,827	3,347	1,852	2,405	10,431	1,690	12.00	+30.35
9	Ammonium sulphate, 150 pounds	2,250	2,502	1,885	2,535	9,172	975	6.00	+18.37
10	None	1,625	1,397	1,495	[1] 1,300	5,817	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to spring crop only—Continued.

1911—SERIES A.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,430	1,332	1,300	1,592	5,654			
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,267	1,527	1,300	1,690	5,784	76	$5.55	−$3.65
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,852	2,112	1,202	1,527	6,693	498	9.30	+ 3.15
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,917	2,372	1,202	1,625	7,116	856	8.25	+13.15
5	None	1,202	1,365	1,267	1,690	5,524			
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,147	2,470	1,267	1,690	7,574	1,019	11.55	+13.92
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,085	3,510	1,300	1,755	9,650	2,124	23.10	+30.00
8	Ammonium sulphate, 300 pounds	2,957	3,380	1,527	2,080	9,944	2,319	12.00	+45.97
9	Ammonium sulphate, 150 pounds	2,535	2,730	1,657	2,242	9,164	1,831	6.00	+39.77
10	None	1,560	1,690	1,397	1,755	6,402			

1912—SERIES A.

Plat.	Fertilizer.	Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,430	[1] 1,495			2,925			
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,490	1,690			3,180	0	$5.55	−$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,345	2,567			4,912	569	9.30	4.92
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,795	2,665			5,460	667	8.25	8.42
5	None	1,430	1,852			3,282			
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,470	2,405			4,875	407	11.55	− 1.38
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,705	3,445			7,150	1,447	23.10	13.07
8	Ammonium sulphate, 300 pounds	4,420	4,095			8,515	2,097	12.00	40.48
9	Ammonium sulphate, 150 pounds	3,315	3,315			6,630	1,317	6.00	26.92
10	None	1,885	2,145			4,030			

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops.

1909—SERIES B.

Plat.	Fertilizer.	Yield per acre.					Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.			
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	2,242	[1] 2,015	7,019	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,641	1,625	2,450	3,282	8,998	57	$11.10	−$9.68
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,450	3,867	10,046	1,024	18.60	+ 7.00
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	3,185	4,582	12,007	1,860	16.50	+30.00
5	None	1,267	1,543	2,340	3,575	8,725	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	3,770	4,582	12,544	1,974	23.10	+26.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	3,542	5,070	14,331	3,177	46.20	+33.22
8	Ammonium sulphate, 300 pounds	2,405	2,730	3,575	5,200	13,910	3,080	24.00	+53.00
9	Ammonium sulphate, 150 pounds	1,950	2,285	3,250	4,940	12,425	2,375	12.00	+47.37
10	None	1,379	1,528	2,210	3,055	8,172	....	....	....

1910—SERIES B.

Plat.	Fertilizer.	Spring Straw.	Spring Paddy.	Fall Straw.	Fall Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,722	[1] 1,495	1,560	[1] 1,495	6,272	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,755	1,430	2,145	2,470	7,800	0	$11.10	−$11.10
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,632	2,860	2,405	3,055	10,952	1,073	18.60	+ 8.22
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,405	2,860	2,470	3,445	11,180	1,463	16.50	+ 20.07
5	None	1,755	2,080	2,145	2,762	8,742	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,307	2,892	2,665	3,835	11,699	1,885	23.10	+ 24.02
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium, sulphate, 240 pounds	3,055	3,705	3,250	4,267	14,277	3,130	46.20	+ 32.05
8	Ammonium sulphate, 300 pounds	3,185	3,900	3,055	4,322	14,462	3,380	24.00	+ 60.50
9	Ammonium sulphate, 150 pounds	2,470	2,827	2,967	3,867	12,131	1,852	12.00	+ 34.30
10	None	1,722	[1] 1,690	1,495	[1] 2,015	6,922	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops—Continued.

1911—SERIES B.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Yield per acre. Spring crop. Paddy.	Yield per acre. Fall crop. Straw.	Yield per acre. Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,625	[1] 910	1,755	[1] 2,535	6,825	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,397	1,397	1,787	2,470	7,051	15	$11.10	−$10.78
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,307	2,502	2,242	3,022	10,073	1,672	18.60	+ 23.20
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,502	2,600	2,405	3,445	10,952	2,193	16.50	+ 38.32
5	None	1,332	1,527	1,675	2,437	6,953	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,600	3,055	2,600	3,737	11,992	2,940	23.10	+ 50.40
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,835	4,485	3,347	4,647	16,314	5,280	46.20	+ 85.80
8	Ammonium sulphate, 300 pounds	3,900	4,420	3,185	4,615	16,120	5,183	24.00	+105.57
9	Ammonium sulphate, 150 pounds	2,535	3,152	2,665	3,900	12,252	3,200	12.00	+ 68.00
10	None	1,430	1,820	1,365	1,917	6,532	....	....	....

1912—SERIES B.

Plat.	Fertilizer.	Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,430	1,755	....	....	3,185	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,495	1,885	....	....	3,380	0	$5.55	—$5.56
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,730	2,665	....	....	5,495	683	9.30	7.77
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	3,055	2,990	....	....	6,045	1,008	8.25	16.96
5	None	1,560	2,047	....	....	3,607	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	3,120	2,925	....	....	6,045	943	11.55	12.02
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	5,330	4,322	....	....	9,652	2,340	23.10	35.40
8	Ammonium sulphate, 300 pounds	4,680	4,095	....	....	8,775	2,113	12.00	40.82
9	Ammonium sulphate, 150 pounds	4,877	3,120	....	....	7,995	1,138	6.00	22.45
10	None	Lost.	2,145	....	....	....	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Summary of the results of applying fertilizers to seven crops of rice.

Plat.	Fertilizer per crop.	Series A—one application annually.				Series B—two applications annually.				
		Paddy.		Total cost of fertilizer.	Total profit or loss.	Paddy.		Total cost of fertilizer.	Total profit or loss.	Average profit (+) or loss (—) per acre.
		Total.	Increase.			Total.	Increase.			
		Pounds.	*Pounds.*			*Pounds.*	*Pounds.*			
1	None	[1] 10,560				[1] 11,567				
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	13,519	26	$22.20	—$21.55	14,559	0	$38.80	—$38.80	—$5.54
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	14,419	926	37.20	— 14.05	19,978	4,908	65.10	57.60	+ 9.39
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	16,134	2,641	33.00	33.02	22,050	6,980	57.75	116.75	+16.69
5	None	13,857				15,971				
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	16,668	3,175	46.20	33.17	23,268	8,198	80.85	124.10	+17.73
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	20,084	6,591	92.40	72.37	29,453	14,383	161.70	197.87	+28.27
8	Ammonium sulphate, 300 pounds	21,352	7,859	48.00	148.47	29,282	14,212	84.00	271.30	+38.76
9	Ammonium sulphate, 150 pounds	19,476	5,983	24.00	125.57	24,091	9,021	42.00	183.52	+26.22
10	None	13,130				14,170				

[1] Injured by cold water flowing directly onto plat. Not included in averages.

The results of these experiments justify the conclusion that for the present at least this soil is in need of nitrogen only. Little or no effects were produced in any case from the use of superphosphate or potassium sulphate, either when applied with or without ammonium sulphate. It is the custom of the rice growers to apply fertilizer, when used at all, to the spring crop only, believing that the more unfavorable weather conditions at that time necessitate the use of stimulants, whereas under the more favorable conditions that prevail during the late summer and early fall fertilizers are less needed. Moreover, it has been considered that the residual effect resulting from the spring application makes itself felt in the fall crop. The above experiments prove conclusively that neither of these opinions is justified. The growth of the fall crop, when more favorable weather prevailed—i. e., higher temperature and longer days—was affected to approximately as great extent by ammonium sulphate as was that of the spring crop. On the whole there appeared no evidence of a cumulative effect even from the heaviest application when made twice annually.

From the data showing the profit and loss it is noteworthy that the application of 300 pounds of ammonium sulphate proved the most economical, either when applied to the spring crop only or to both spring and fall crops, and that in the latter case the profits were very large. So far as these experiments go, they show in addition that the yields can be maintained at a high point and good profit be made under the system now employed, provided the proper fertilizer be used. This is not to be interpreted, however, as being a recommendation of the system now in use, since it has been shown (p. 19) that with the rotation of crops, involving the plowing under of a legume, still greater yields can be obtained. The rotation system is far more rational and permanent and ought to be employed on all rice lands.

It has been found in other countries that the continued application of ammonium sulphate tends to produce acidity in the soil due to the fact that the sulphate ion tends to accumulate in the soil. The occasional application of lime, however, will correct this defect. The highly basic character of Hawaiian soils, on the other hand, particularly the rice soils, justifies the belief that the production of acidity from the use of ammonium sulphate will be far removed in point of time. It is of interest in this connection that the annual application for over 60 years of 300 pounds of ammonium sulphate per acre at Rothamsted to a soil containing considerable amounts of calcium carbonate (probably 100 tons per acre in the first 7 inches) has not produced injurious acidity. The soil on which the above rice experiments were conducted contains a relatively high percentage of lime and magnesia, particularly the latter, but neither of these is present as carbonate in more than very limited amounts. The carbon dioxid content of the soil is low, not more than 0.10 per cent. The iron and aluminum, however, occur largely as hydrates which give to the soil its basic character, and which we may reasonably believe will prevent the accumulation of injurious acidity. It is of further interest to note that the application of lime has been shown to cause a decrease in the yields of rice on this soil.

It would not be safe, however, to recommend ammonium sulphate as the only fertilizer to be applied to the rice lands of the islands generally, since the effects of fertilizers frequently vary widely on different soils. In order to throw further light on this question some experiments have been conducted cooperatively on other rice lands, which resulted in showing that ammonium sulphate produced practically as large increases as a complete fertilizer. At Kailua, for instance, approximately 60 per cent increase in yield was produced both by 150 pounds of ammonium sulphate and by a complete fertilizer containing an equal amount of ammonium sulphate.

As already pointed out, the rice soils, as a rule, are rich in phosphoric acid but contain relatively small amounts of potash. While it is true that rice takes up a large amount of potash only a compara-

tively small part of it enters the grain. In addition, only a comparatively small portion of the straw is really removed from the land, it being the practice to leave about one-half of it on the ground at the time of harvesting, while the remaining portion is used for bedding, etc., a large part of which sooner or later is returned to the soil. Furthermore, whenever manure is accessible the Chinese rice growers cart large quantities of it onto the lands, thus considerably augmenting the potash supply. In view of these facts, then, it is hardly to be supposed that potash fertilizer will be required for many years. In the main, therefore, nitrogen fertilizers only are recommended for Hawaiian rice lands.

In this connection the question of the form of nitrogen best suited to rice naturally arises. Experimental data have been obtained on this subject which permit the drawing of definite conclusions.

THE FORM OF NITROGEN FOR RICE.

One of the most generally accepted teachings in all agricultural literature, based, however, mainly upon experiments with dry-land crops, is that of the high availability of nitrates, it being considered that of all the forms of nitrogen nitrate is the most readily taken up from the soil and used as food by plants. As a result of the prevalence of this view nitrates have been used for rice in America, and indeed sodium nitrate still is recommended at the present time for this crop by some authorities.

It has been known in oriental countries for some time, however, that nitrate is not the most profitable form of nitrogen to apply to rice. Nagaoka,[1] in Japan, demonstrated in 1905 the superiority of ammonium sulphate in a series of pot experiments. He found that while the effects produced by nitrates were variable and discordant the yields were greatly increased in every instance by the use of ammonium sulphate. As a result of his experiments Nagaoka concluded that the value of ammonium sulphate and nitrates stand in the ratio of 100 to 40.

In 1907 Daikuhara and Imaseki [2] also found ammonium sulphate to be much more effective for wet-land rice than either sodium nitrate alone or a combination of the two forms. The value of nitrate was also found to be considerably less when applied in conjunction with organic manures. Likewise it has been shown in several of the Provinces of India that other forms are superior to nitrates. Coleman and Ramachandra Rao,[3] for example, pointed out that organic fertilizers produced a marked stimulation of the growth of rice in Mysore, while niter had but little effect. In 1911 the writer [4] pub-

[1] Bul. Col. Agr., Tokyo Imp. Univ., 6 (1904), pp. 285–334.

[2] Bul. Imp. Cent. Agr. Expt. Sta. Japan, 1 (1907), No. 2, pp. 7–36.

[3] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.

[4] Hawaii Sta. Bul. 24.

lished the results of experiments conducted at the Hawaii station which showed the great superiority of ammonium sulphate over different nitrates.

Notwithstanding these facts some American writers continue to recommend sodium nitrate for rice and to discuss rice soils from the same standpoint as dry lands.

It is not necessary to go into a theoretical discussion of this question at this time further than to state that abundant experimental evidence has already been brought forth in various parts of the world to prove that nitrate is not the only form of nitrogen available to plants. Results obtained at the Hawaii station show that nitrate can hardly be considered to be the principal source of combined nitrogen for many plants when grown in the state of nature. It is known that nitrates are ill suited to assimilation by rice.

To study the practical effects produced on the growth of rice by ammonium sulphate and nitrate nitrogen, respectively, a series of plats was arranged alongside of those used in the experiments discussed above. To one plat ammonium sulphate and to another nitrate of soda was applied before the time of planting. To other plats ammonium sulphate and sodium nitrate were applied in smaller quantities, the same being repeated at intervals of 10 days until six applications had been made. To each plat the total amount of nitrogen applied per acre was the same, and the experiments were repeated for three successive crops. The results follow:

Comparison of ammonium sulphate and sodium nitrate on rice.

Nitrogen applied.	Fall crop, 1909.			Spring crop, 1910.			Fall crop, 1910.		
	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Ammonium sulphate (applied before planting)	3,168	4,603	7,771	3,316	3,564	6,880	2,920	4,010	6,930
Sodium nitrate (applied before planting)	1,881	2,475	4,356	2,029	2,128	4,157	2,227	3,312	5,539
Ammonium sulphate (applied in six applications)	2,475	3,465	5,940	2,772	3,078	5,850	2,722	3,762	6,484
Sodium nitrate (applied in six applications)	2,277	2,623	4,900	1,633	2,079	3,712	1,831	2,427	4,258
Check				1,930	2,178	4,108	2,145	2,762	4,907

From the above yields it is apparent that nitrate of soda produced only slight increases either when applied before transplanting or at intervals during the growth of the crop. Ammonium sulphate, on the other hand, brought about notable increases in every instance, the larger harvests having been obtained from the single application before planting. The repeated applications were made for the purpose of guarding against the loss of nitrate through leaching, but this appeared to have no advantage over the single application.

From pot experiments, where drainage was entirely prevented, the great superiority of ammonium nitrogen over nitrate was again demonstrated. In a series of pot experiments with the use of sterile quartz sand, it was found that where nitrate was the only form of combined nitrogen present rice made very poor growth, whereas ammonium forms seemed to be well suited to its needs. The net result of all these experiments forces the conclusion that nitrate is not a suitable form of nitrogen for rice, but that ammonium compounds are well adapted to its needs.[1]

In the rice-producing countries of the Orient organic manures are the chief source of nitrogen applied to rice soils. It has long been the custom of the Chinese and Japanese to grow some legume between crops for the purpose of enriching the soil. Sometimes the legume is grown on one field, cut, and then distributed over others, so as to gain the benefit of green manuring with as little interruption in the growing of rice as possible. In addition, all sorts of organic nitrogenous substances are freely applied. In Hawaii, on the other hand, almost no rotation is practiced.

From a single experiment conducted by the agronomist of this station, however, it was found that by plowing under a few months' growth of alfalfa just previous to the planting of rice the yield was 50 per cent greater than has ever been obtained on this soil by the application of any commercial fertilizer. In this experiment the alfalfa was grown on one plat, but was cut and applied to another, so that the effects may be attributed to the organic manure directly rather than to a combination of aeration and other effects, the soil being prepared and submerged very soon after making the application. Moreover, the application of different organic nitrogenous fertilizers at various times has always resulted in substantial increases in the yield of rice on this soil. In a series of pot experiments, for example, soy-bean cake was compared with ammonium sulphate. In this experiment nitrogen from each of the two sources was applied at the rate of 70 pounds per acre. The yields obtained were as follows:

Ammonium sulphate versus soy-bean cake as fertilizers for rice.

Treatment of plat.	Straw.	Paddy.	Total.
	Grams.	*Grams.*	*Grams.*
Ammonium sulphate	215	138	353
Soy-bean cake	167	122	289
Check	80	61	141

From the above data it will be seen that soy-bean cake brought about an increase of 100 per cent in the yield, but was considerably inferior in this respect to ammonium sulphate. The reasons for the

[1] The full data with reference to the assimilation of different forms of nitrogen by rice and a more complete bibliography of this subject will be found in Hawaii Sta. Bul. 24.

superiority of ammonium sulphate over organic forms of nitrogen are discussed in greater detail on page 21. In this connection it is of interest to point out that the plant absorbs the principal part of its nitrogen during the early period of its growth;[1] readily available nitrogen therefore is needed when the rice is young, and since the production of available nitrogen from organic forms requires considerable time the application should be made some time in advance of planting, a precaution that was not taken in the above experiments. Through a period of years, however, the total effects would probably become more nearly equal.

AMMONIFICATION AND NITRIFICATION IN RICE SOILS.

The analysis of a number of rice soils taken from the field when wet and analyzed immediately has shown that rice soils contain considerable quantities of ammonia, varying from a few parts up to as much as 50 or 60 parts per million.[2] On the other hand, in the submerged condition nitrate is rarely found in more than mere traces, frequently being entirely absent.

Since good effects are known to follow the use of organic manures, and, furthermore, that ammoniacal nitrogen is especially effective with rice, it becomes a matter of interest to ascertain whether or not ammonia is formed in rice soils at rates sufficient to supply the needs of rice.

Accordingly a series of ammonification experiments were carried out with dried blood as the source of nitrogen, using varying amounts of water, starting in with the air-dry condition and increasing the amounts of water applied up to and beyond the saturation point. One hundred gram portions of soil were placed in tumblers with 2 grams of dried blood added to each. After an incubation period of seven days the ammonia was determined by distilling with magnesium oxid into standard acid. The results obtained were as follows:

Influence of varying amounts of water on the ammonification of dried blood.

Water added.	Nitrogen found as ammonia.		Water added.	Nitrogen found as ammonia.	
	Soil 292.	Soil 461.		Soil 292.	Soil 461.
	Mg.	*Mg.*		*Mg.*	*Mg.*
None (soil air dry)[3]	2.2	3.9	35 cc.	131.1	86.8
5 cc.	2.2	5.1	40 cc.	90.5	85.4
10 cc.	37.8	4.3	45 cc.	[4] 54.5	71.2
15 cc.	164.9	25.5	50 cc.	50.7	65.3
20 cc.	165.5	41.2	55 cc.	48.2	52.4
25 cc.	164.6	53.2	65 cc.		[4] 15.1
30 cc.	140.1	59.0	70 cc.		16.1

[1] Hawaii Sta. Bul. 21.

[2] Fraps also showed in 1906 that ammonification takes place much more vigorously in rice soils of Texas than does nitrification (Texas Sta. Bul. 82).

[3] Each soil contained about 5 per cent moisture.

[4] Saturated.

It is here seen that ammonification proceeded at a slow rate only, if at all, until a certain moisture content was reached (about 10 per cent in the case of soil 292 and 15 per cent with that of 461), above which vigorous ammonification took place, which steadily increased up to an approximate two-thirds saturation, then decreased as complete saturation was approached. There was, however, active ammonification in the completely saturated soils. This seems to prove that ammonia is formed in submerged soils and that organic nitrogenous fertilizers will give rise to nitrogen available to rice under conditions that prevail in rice cultures.

As is well known, the formation of ammonia results from the activity of a wide range of soil organisms, bacteria and fungi, some of which are aerobic and some anaerobic. While the above data show that ammonification is more active with moisture supplies below the saturation point, being greatest at approximately two-thirds saturation; nevertheless, the fact that ammonification can take place in saturated soils is of very great importance in the growth of rice. It makes possible the production of available nitrogen in rice soils without the necessity of employing cultural methods that are primarily designed to bring about aerated conditions.

Free oxygen being essential to nitrification, it seems justifiable to conclude that nitrification does not take place to any considerable extent in a submerged soil. In order to throw positive light on the question, however, search was made for nitrates in various submerged soils about Honolulu, but in no instance was more than a few parts per million found. In some laboratory experiments it was further found that practically no nitrification took place in submerged soils.

The process of denitrification, however, is of considerable importance in this connection. As is well known, free nitrogen gas may be one of the products of the decay of organic manures. Likewise, it is also known that certain denitrifying bacteria break down nitrates into nitrites, ammonia, and finally into free nitrogen gas. The conditions under which the denitrifying bacteria function are extremely varied, but the two conditions most favorable for their activity are a source of food supply and a lack of free oxygen. In the rice soils of Hawaii these conditions are abundantly met; the high content of organic matter guarantees a source of food, while supersaturation excludes the air.

As indicated above, the denitrification processes may be conveniently divided into two classes, (1) those causing a liberation of nitrogen from organic materials, and (2) those bringing about a reduction in the nitrates present. The latter of these has been the subject of considerable study at the Hawaii station.

In pot experiments conducted some time ago for the purpose of studying the nutritive value of different forms of nitrogen it was found that in every instance the addition of nitrate to submerged soil resulted in the formation of comparatively large amounts of nitrite within a few days after the time of application. In sand cultures similar effects were observed except where complete sterilization was effected. Furthermore, wherever any considerable amount of nitrite was formed, more than 5 to 6 parts per million, toxic effects were produced, while still greater amounts caused the rice to turn yellow and later to die.

Nitrite, however, was not produced to any considerable extent when organic ammoniacal nitrogen was the only form of combined nitrogen present. A further objection to the use of nitrates as fertilizer for rice is found in the fact, therefore, that nitrates become reduced to nitrites, which are extremely poisonous to rice. Nitrate, then, is unsuited to the nutrition of rice, and in turn may give rise to a substance that is distinctly poisonous.

THE MANAGEMENT OF RICE SOILS.

During the past few years an increasing amount of study has been given to the question of soil management and cultural methods, the rotation of crops, and various methods of soil treatment are coming to be viewed in their relation to this general question. Investigations on special phases of this subject have thrown new light on the important question of soil fertility in general and on that of submerged soils in particular.

In an investigation on the solubility of the island soils[1] some data of interest in this connection were recently obtained. Likewise Coleman and Ramachandra Rao[2] studied the effects on the yield of rice of aerating the soil.

The solubility of substances in submerged soils has been found to be abnormally high, the amounts of the several mineral constituents going into solution in water having been found to be considerably greater than were obtained from any of the dry-land soils of the islands.[1] After the wet soil was allowed to thoroughly dry out, however, the solubility in water was found to be greatly decreased, falling to about the same degree as that of dry lands. Similar data have also been obtained by Coleman and Ramachandra Rao, in Mysore.[2] This seems referable in the main to soil colloids and the formation of soil films in the air-dried state. The overcoming of film pressure and diffusion of dissolved materials upon resubmergence require considerable time, so that the amount of soluble plant

[1] Hawaii Sta. Bul. 30.
[2] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.

food coming into contact with the absorbing root surfaces of rice would be considerably less when planted in a soil that had been thoroughly dried out. Later the mineral constituents would, of course, regain their former state of solubility, but just how much time would be required for the reestablishment of a permanent concentration can not be definitely stated. It seems certain, however, that a lowering of the availability of the mineral constituents would temporarily result from a thorough drying out of the soil.

It is now the practice of the growers, both on the mainland and in Hawaii, to plow their rice lands some weeks before the flooding time, in the latter case immediately following each harvest, so as to permit as much aeration of the soil as possible. As would be expected the aeration prevents nitrification, so that by the time a new crop is planted nitrate has accumulated to a considerable extent. Upon resubmergence the nitrate thus formed becomes partially leached out of the soil and in part converted into poisonous nitrites. The nitrification therefore leads to a direct loss of nitrogen on the one hand and to the formation of a substance toxic to rice on the other. If, however, Hawaiian rice soils are not plowed or cultivated after the water is turned off and the previous crop harvested little or no nitrification sets in. The puddled state of the soil and its compacted condition effectively exclude air. It is only after cultivation and consequent aeration that active nitrification sets in.

Unfortunately no experiments showing the practical effects on the growth of rice as produced by aeration against nonaeration have been conducted at this station. Such experiments, however, have been made in Mysore, the results of which are in complete harmony with the inferences drawn from the nitrogen transformations above referred to. As a result of experiments carried on through two years, Coleman and Ramachandra Rao[1] found that a considerable gain in the yield of rice was obtained by leaving the land in the unplowed condition during the time between crops, the plowing for the new crop being deferred until just before the new crop was planted. By growing a legume between rice crops all needed aeration can be brought about; while the nitrates formed during this period would be absorbed to a large extent by the legume, and in addition free nitrogen from the air would be added to the soil through the growth of the legume. Upon plowing under the legume ammonification will set in, thus furnishing available nitrogen for the next rice crop. The nitrogen requirements of the rice would therefore be met and other beneficial effects that are believed to result from the rotation of crops would be secured. There is little ground

[1] Loc. cit., p. 9.

to doubt that better conditions would thus be established and greater profits obtained.

In the carrying out of the experiments reported in this bulletin assistance has been rendered by various members of the station staff, to whom thanks are hereby extended.

SUMMARY.

(1) Hawaiian rice soils have originated from basaltic lava, but also contain small amounts of coral limestone.

(2) In texture most of the rice lands are clay loams, and contain approximately equal quantities of fine sand, silt, fine silt, and clay.

(3) In chemical composition these soils are quite similar, with the exception of those from the Waikiki and Kaulaunui districts, the former of which contain abnormal amounts of magnesia, while the latter are highly organic. In general, the nitrogen and phosphoric acid are high, while the potash is low, due largely to the solubility of potash, which is leached from the soil.

(4) From fertilizer experiments carried on through seven crops it was found that the application of 150 pounds per acre of ammonium sulphate produced notable increases in the yield, but 300 pounds per acre proved the more profitable. Potash and phosphoric acid were without effect. The application of ammonium sulphate to both the spring and fall crops yielded considerably more profit than when made to the spring crop only. The residual effects on the fall crop from the spring application are small. The immediate effects obtained from making the application to the fall crop were about the same as those obtained with the spring crop.

(5) A complete fertilizer proved no more effective than ammonium sulphate alone, whereas the application of both ammonium sulphate and potassium sulphate caused a decrease as compared with that obtained from ammonium sulphate alone.

(6) Nitrogenous fertilizers only are recommended for Hawaiian rice soils, and for immediate effects a given amount of nitrogen in the form of ammonium sulphate will produce greater returns than from organic sources. Under no circumstances should nitrates be used as fertilizer for rice.

(7) With nitrate as the only source of combined nitrogen for rice poor growth results. In addition nitrates in submerged soils become reduced to nitrites, which are poisonous to rice. Ammoniacal nitrogen, on the other hand, is well suited to the needs of rice.

(8) Very little nitrification takes place in submerged soil: ammonification, however, goes on, not so vigorously as in aerated soils, but sufficiently to supply the nitrogen needs of rice, provided sufficient organic matter is present in the soil.

(9) A rotation of crops, including the plowing under of a legume, is recommended. It is believed a system can be worked out whereby a legume can be grown between crops and then plowed under, thus gaining the benefits of the rotation and at the same time permitting the growing of two crops of rice annually.

(10) Rice soils should not be plowed and then allowed to lie fallow between crops. Nitrification sets in immediately after aerated conditions are produced and the nitrates thus formed become converted into poisonous nitrites upon resubmergence, or are lost through leaching. When no rotation is practiced it is better to leave the land unplowed until just before planting the next crop.

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E. V. WILCOX, Special Agent in Charge.

Bulletin No. 31.

RICE SOILS OF HAWAII:

THEIR FERTILIZATION AND MANAGEMENT.

BY

W. P. KELLEY,

CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1914.

HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *October 1, 1913.*

SIR: I have the honor to submit herewith and recommend for publication, as Bulletin No. 31 of the Hawaii Agricultural Experiment Station, a paper on Rice Soils of Hawaii: Their Fertilization and Management, by W. P. Kelley, chemist. The experiments on rice as carried out by this station indicate quite conclusively that for the most successful production of rice all conditions which tend toward nitrification should be avoided. The application of nitrates has been found to be of little or no avail, and sometimes even positively injurious, while the use of ammonium sulphate brings about greatly increased yields. In harmony with this finding is the evidence that conditions which allow nitrification to take place in rice soils result in a diminished yield of rice. It appears, therefore, that ammonium sulphate should be the form of commercial nitrogen to apply to rice and that rice soils should not be aerated between crops. These results are probably applicable to other regions than the rice lands of Hawaii.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

RICE SOILS OF HAWAII: THEIR FERTILIZATION AND MANAGEMENT.

INTRODUCTION.

The extensive soil investigations that have been made up to the present time have dealt principally with dry lands, in which the moisture and other conditions differ greatly from those prevailing in rice soils. In America in particular very little study has been devoted to submerged lands, and little, indeed, is really known about them. Consequently recommendations for the treatment and management of rice soils are generally based on knowledge gained from experience with dry lands. It is evident, however, that conclusions applicable to dry soils do not necessarily apply to submerged soils such as are used in rice culture, and, in fact, it is well known in oriental countries that rice lands demand different treatment from those devoted to dry-land cultures.

The one condition that is most obviously different in rice soils and dry lands is that of aeration. The fact that aeration is essential to the successful growth of most crops, and the belief that fertility is in some way dependent upon its maintenance, has caused agriculturists to recommend for rice soils practices designed to secure aeration in the belief that this is as essential for successful rice culture as for culture of other crops. Experiments are not wanting, however, which show this to be untrue.

One of the most important matters affecting the culture of rice is the form in which nitrogen is taken up by the crop. It is well known that the degree of aeration in soils determines very largely the form assumed by available nitrogen. This phase of the subject has been reported upon previously by the writer,[1] but will be further emphasized in this bulletin on account of the principle involved and the practical importance attached to it.

In connection with the general soil investigations, which have been under way in the laboratory of the Hawaii station for several years, the rice lands of the Hawaiian Islands have received considerable attention. For a number of years also field experiments with different

[1] Hawaii Sta. Bul. 24.

fertilizers for rice have been conducted by the station. The subject has been approached from a number of standpoints, both practical and scientific, and it is believed the results are of sufficient interest and value to warrant publication at this time.

ORIGIN OF RICE SOILS.

The rice soils of Hawaii are located at or near sea level along the coast and are not extensive in area, amounting to about 10,000 acres, and during recent years the tendency has been to plant other crops on some of the lands hitherto devoted to rice because of low yields, labor difficulties, etc. The extent of the industry, therefore, is on the decline. The soils have their primary origin in basaltic lavas, just as is the case with all the soils of the islands, but in addition they frequently contain varying amounts of coral lime ($CaCO_3$), which has become thoroughly mixed with the lava residues. Whether or not the coral is visible on the surface, in practically all cases the rice lands are underlain at various depths with deep beds of coral limestone. Notwithstanding the fact that the lavas are typical basalts, the chemical and physical properties vary enormously; moreover, the rates of disintegration and the composition of the residuum differ greatly from place to place. Therefore the soils coming from lavas of essentially the same type may be very different in composition and properties. The low lands in and around Honolulu, for instance, having been derived from the disintegration of volcanic cinder, typical black sands, are widely different from the rice lands on the leeward side of Oahu, both in chemical and physical properties. This is especially noticeable in the relative percentages of lime and magnesia.

In most instances the rice soils are strictly alluvial, although on account of the close proximity of the mountains there has been but a limited transportation of the soil materials. The soils in places contain a high percentage of organic matter.

In certain localities, as, for instance, the Hanalei Valley, on Kauai, the soils contain high percentages of clay and are of a close texture. The rice lands around Honolulu, on the other hand, contain quantities of sand and gravel unusual for Hawaiian soils, and as a consequence are open and porous. Samples of soil from all the important rice sections have been examined.

MECHANICAL COMPOSITION.

In view of its bearing on irrigation, etc., the mechanical composition as shown by physical analysis has been determined and is recorded in the following on page 5.

Physical analyses of rice soils.

District.	Fine gravel, 2–1 mm.	Coarse sand, 1–0.2 mm.	Fine sand 0.2–0.04 mm.	Silt, 0.04–0.01 mm.	Fine silt, 0.01–0.002 mm.	Clay, 0.002 mm. or less.	Organic matter and combined water.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Waikiki:							
Soil 292	20.91	18.75	22.04	8.69	12.41	7.23	8.71
Subsoil 293	18.61	18.30	22.74	8.10	13.48	9.52	10.77
Fort Shafter:							
Soil 332	1.15	1.61	18.34	16.28	23.88	25.39	14.37
Subsoil 333	1.02	1.28	20.63	17.88	22.11	24.06	14.05
Soil 334	.62	1.63	15.33	15.77	21.73	31.61	15.23
Kailua:							
Soil 337	.35	.69	18.78	13.57	22.92	25.70	18.72
Subsoil 338	.33	.86	18.60	15.97	21.97	23.97	19.54
Soil 339	.13	.22	18.13	20.42	22.37	19.19	21.17
Subsoil 340	.06	.31	16.75	19.27	23.42	22.98	19.41
Kaneohe:							
Soil 343	.05	.19	16.03	30.79	14.64	20.16	15.44
Subsoil 344	.22	.11	15.29	28.94	20.67	21.73	13.20
Waiahole:							
Soil 345	.15	3.09	25.94	20.97	15.96	19.84	15.04
Subsoil 346	.46	3.59	34.44	19.30	10.96	14.29	15.31
Kalaunui:							
Soil 347	.41	.83	21.49	27.45	7.61	6.38	36.14
Subsoil 348	.22	.64	11.29	15.27	20.07	6.19	49.24

The above data show that the rice soils of Oahu, with the exception of those from the Waikiki and Kalaunui districts, are very similar in mechanical composition, and are made up of approximately equal quantities of fine sand, silt, fine silt, and clay. The Waikiki soils, on the other hand, contain relatively small amounts of clay, with correspondingly larger amounts of the coarser grained particles. None of the soils except from this district contains any material coarser than fine gravel, while that from Waikiki contains several per cent of stones, etc. This point is of importance because of its bearing on tillage and drainage. The soils from Kalaunui, on the other hand, are very highly organic, and in places this land is peaty to a considerable degree. The organic matter of this soil, however, retards the passage of water through it, with the result that the amounts of water used in its irrigation are practically normal for the islands.

In the main these soils are to be classified as clay loams with a rather high organic content. The irrigation of all these soils requires relatively large amounts of water on account of their porous nature.

In considering the mechanical composition of Hawaiian soils it should be especially borne in mind that the terms clay, fine silt, etc., have reference only to the size of the particles, and that these are made up of different chemical substances from those that go to make up clay in most continental soils. Furthermore, the properties of so-called clay in Hawaiian soils differ from the properties of other clays. It is not composed primarily of kaolin, but is made up of ferric and aluminum hydrates, together with double silicates of iron and aluminum and perhaps some aluminum silicate. In

addition the coarser particles are in the main merely lava fragments on their way toward more complete disintegration. These frequently show under the microscope the characteristic structure of lava. As time goes on the relative proportions of these constituents will change, so that eventually a higher percentage of clay and fine silt will predominate. The upland soils at the present time frequently contain practically no material coarser than silt, with abnormally large quantities of clay. The soils are typical laterites,[1] and in interpreting the analytical results reported herein it is important to bear this in mind.

CHEMICAL COMPOSITION.

The chemical composition of these soils, as determined by the use of the official methods, is shown in the following table:

Chemical composition of rice soils.

District.	Insoluble matter.	Potash (K_2O).	Soda (Na_2O).	Lime (CaO).	Magnesia (MgO).	Manganese oxid (Mn_3O_4).	Ferric oxid (F_2O_3).
OAHU.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Waikiki:							
Soil 292	41.69	0.42	1.47	1.99	9.42	0.27	18.01
Subsoil 293	38.82	.47	1.36	2.48	9.75	.21	21.22
Fort Shafter:							
Soil 332	44.57	.25	.46	.97	.94	.32	18.84
Subsoil 333	45.75	.26	.36	.87	.58	.30	18.48
Soil 334	44.94	.27	.34	.81	.99	.13	17.56
Kailua:							
Soil 337	40.53	.26	.45	.76	.82	.09	19.01
Subsoil 338	42.60	.16	.46	.59	.49	.27	19.67
Soil 339	37.20	.14	.44	.43	.26	.08	24.80
Subsoil 340	38.20	.06	.37	.47	.31	.11	26.15
Kaneohe:							
Soil 343	50.10	.10	.36	1.22	.87	.51	11.20
Subsoil 344	51.15	.15	.38	1.65	.73	.52	10.50
Waiahole:							
Soil 345	50.52	.09	.24	1.20	1.08	.42	17.25
Subsoil 346	48.30	.08	.28	1.63	1.54	.45	16.18
Kalaunui:							
Soil 347	37.82	.12	.31	2.20	.79	.32	7.05
Subsoil 348	27.70	.09	.32	2.76	.78	.35	6.44
KAUAI.							
Hanalei Valley:							
Soil 460	42.40	.16	.10	1.16	2.67	.09	16.22
Soil 461	40.40	.27	.10	.97	3.35	1.16	17.10
Soil 462	47.25	.19	.41	1.18	2.28	.02	14.82
Soil 463	47.00	.17	.34	.97	6.98	.04	18.20
Soil 464	45.18	.15	.42	1.26	1.72	.14	15.32
Soil 465	45.70	.14	.45	1.38	2.65	.23	15.23
Soil 466	45.35	.15	.29	.96	4.16	.15	18.16
Soil 467	43.30	.17	.34	1.16	3.07	.13	15.91

[1] The decomposition of basaltic lavas usually gives rise to soils high in iron and aluminum and relatively low in silica, and while the most finely divided particles are usually referred to as clay, the name is improperly applied. Recently Ulpiani (Staz. Sper. Agr. Ital., 45 (1912) pp. 629-653) suggested that this process be called lateritization in contradistinction to kaolinization, which takes place in the decomposition of orthoclase feldspars.

Chemical composition of rice soils—Continued.

District.	Alumina (Al_2O_3).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Titanic dioxid (TiO_2).	Loss on ignition.	Total.	Nitrogen (N).
OAHU.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Waikiki:							
Soil 292	14.10	0.62	0.08	2.17	9.10	99.31	0.16
Subsoil 293	13.09	.71	.11	2.64	9.92	100.78	.16
Fort Shafter:							
Soil 332	17.10	.32	.03	2.26	13.96	100.02	.16
Subsoil 333	17.42	.26	.10	2.17	13.58	100.13	.13
Soil 334	19.35	.45	.23	1.53	13.70	100.32	.23
Kailua:							
Soil 337	14.94	.76	.26	2.43	18.63	98.94	.44
Subsoil 338	14.50	.68	.26	2.13	18.43	100.24	.42
Soil 339	12.72	.29	.20	2.92	21.10	100.58	.41
Subsoil 340	12.45	.22	.20	2.81	18.41	99.76	.30
Kaneohe:							
Soil 343	20.35	.20	.04	2.24	13.85	100.94	.20
Subsoil 344	20.90	.23	.04	2.37	12.30	100.92	.17
Waiahole:							
Soil 345	14.92	.21	.20	1.64	13.22	100.99	.21
Subsoil 346	15.30	.23	.13	1.60	14.70	100.42	.20
Kalaunui:							
Soil 347	14.40	.19	.31	2.28	34.52	100.31	1.24
Subsoil 348	12.42	.13	.80	1.90	46.70	100.39	1.44
KAUAI.							
Hanalei Valley:							
Soil 460	20.15	.44	.27	2.78	14.15	100.59	.26
Soil 461	20.10	.52	.28	3.00	14.35	101.60	.24
Soil 462	19.12	.53	.35	2.67	12.25	101.07	.20
Soil 463	13.60	.35	.30	2.06	10.42	100.43	.18
Soil 464	20.30	.51	.28	2.93	12.95	101.17	.20
Soil 465	19.95	.72	.31	2.27	11.27	100.30	.15
Soil 466	16.95	.31	.26	2.57	11.80	101.10	.17
Soil 467	20.35	.56	.31	2.70	13.35	101.35	.17

It will at once be seen that these soils differ from normal soils not only in physical properties but also in chemical composition.

The lavas from which these soils have been derived are made up primarily of pyroxenes or amphiboles and soda-lime feldspars, and therefore are characteristically basic. In the disintegration process solution and oxidation play the most important parts, with the result that the soils formed contain iron and aluminum in great quantities, while the potash, soda, lime, and magnesia are largely leached out as silicates. In a few instances the rice soils, however, contain relatively large amounts of lime and magnesia, due partly to admixtures with coral limestone and in part to the type of lava from which they were derived. It is also noteworthy that the ratio of lime to magnesia in these soils is abnormal, the latter sometimes being present in great excess above the former. In view of the interest now taken in the lime-magnesia ratio the relations of these two elements are of special interest, particularly since rice has been extensively studied in connection with this ratio.

The potash content is rather low, while phosphoric acid is generally present in large amounts. From a superficial examination of these analyses it would seem that potash fertilization is needed. It will be shown in connection with the fertilization studies, however, that there

is no need for potash fertilizer. The decomposition of the lava fragments is greatly increased by the products arising from the decay of organic matter under the prevailing anaerobic conditions, with the result that potash is rendered soluble at a rate sufficient to supply the needs of rice, but the limited supply of potash present, together with the fact that large amounts of potash are taken up by rice, will sooner or later necessitate the use of potash-bearing fertilizer.

FERTILIZER EXPERIMENTS.

Some fertilizer experiments with rice have already been published by this station.[1] The results were such as to emphasize the need for a more systematic study of this question, and in view of the fact that the yields obtained by the rice growers throughout the islands are frequently unprofitable, a series of fertilizer tests were instituted on the rice trial grounds of the station in the spring of 1909. These experiments were continued on the same plats throughout seven consecutive crops. In Hawaii little or no rotation of crops is practiced, and two crops of rice are grown on the same land each year.

The soil on which these experiments were made had been previously devoted to rice culture and was known to be quite uniform in productivity. After the plats had been laid out, however, an additional crop, without fertilization, was grown for the purpose of determining more definitely their uniformity. The results showed the plats to be extremely uniform throughout, practically the same yield having been obtained from each. The plats were separated by low dikes so constructed as to prevent the lateral movement of fertilizers and irrigation was adjusted so as to insure a constant water supply of about 2 inches in depth above the surface of the soil.

After harvesting the first crop the original plats were divided into two equal portions, which here are to be designated as series A and B. The former were fertilized previous to the time of transplanting the spring crop only, while the latter received the same applications in like quantities to both the spring and fall crops. Previous experience had suggested that nitrogen would prove to be the most needed element, and this was borne out by the results obtained later. The yields obtained, fertilizers applied, etc., are recorded in the tables, using the following values in calculating the cost of fertilizers, profits, etc.: Ammonium sulphate, \$80 per ton; superphosphate, \$20 per ton; potassium sulphate, \$55 per ton; paddy, \$0.025 per pound. In calculating the profit or loss, the extra expense incurred from the increased labor attached to making the application of fertilizers, harvesting, and marketing the increased yields, etc., was not included.

[1] Hawaii Sta. Rpts. 1907 and 1908.

Results of applying fertilizers to spring crop only.

1909—SERIES A.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Yield per acre. Spring crop. Paddy.	Yield per acre. Fall crop. Straw.	Yield per acre. Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	1,950	[1] 1,950	6,662	....	....	....
2	Superphosphate, 225 pounds; Potassium sulphate, 120 pounds	1,641	1,625	2,242	3,250	8,758	9	$5.55	−$5.33
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,667	2,632	9,028	0	9.30	− 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	2,275	3,217	9,732	479	8.25	+ 3.72
5	None	1,267	1,543	2,275	3,347	8,432	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	2,925	3,347	10,464	723	11.55	+ 6.52
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	2,250	3,152	11,121	1,243	23.10	+ 7.96
8	Ammonium sulphate, 300 pounds	2,405	2,730	2,307	3,315	10,757	1,179	12.00	+17.47
9	Ammonium sulphate, 150 pounds	1,950	2,285	2,502	3,867	10,604	1,286	6.00	+26.15
10	None	1,379	1,528	2,372	3,315	8,594	....	....	....

1910—SERIES A.

Plat.	Fertilizer.	Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,657	1,527	1,560	[1] 1,202	5,946	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,690	1,722	1,852	2,015	7,279	0	$5.55	−$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,950	1,722	1,560	1,852	7,084	0	9.30	− 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,982	2,047	1,820	2,080	7,929	65	8.25	− 6.63
5	None	1,690	1,885	1,755	2,177	7,507	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,917	2,307	1,755	2,307	8,286	552	11.55	+ 2.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,470	3,055	1,820	2,210	9,555	1,203	23.10	+ 6.97
8	Ammonium sulphate, 300 pounds	2,827	3,347	1,852	2,405	10,431	1,690	12.00	+30.35
9	Ammonium sulphate, 150 pounds	2,250	2,502	1,885	2,535	9,172	975	6.00	+18.37
10	None	1,625	1,397	1,495	[1] 1,300	5,817	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to spring crop only—Continued.

1911—SERIES A.

Plat.	Fertilizer.	Yield per acre.						Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.	Increase in paddy per annum.		
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,430	1,332	1,300	1,592	5,654	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,267	1,527	1,300	1,690	5,784	76	$5.55	−$3.65
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,852	2,112	1,202	1,527	6,693	498	9.30	+ 3.15
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,917	2,372	1,202	1,625	7,116	856	8.25	+13.15
5	None	1,202	1,365	1,267	1,690	5,524	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,147	2,470	1,267	1,690	7,574	1,019	11.55	+13.92
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,085	3,510	1,300	1,755	9,650	2,124	23.10	+30.09
8	Ammonium sulphate, 300 pounds	2,957	3,380	1,527	2,080	9,944	2,319	12.00	+45.97
9	Ammonium sulphate, 150 pounds	2,535	2,730	1,657	2,242	9,164	1,831	6.00	+39.77
10	None	1,560	1,690	1,397	1,755	6,402	....	....	....

1912—SERIES A.

Plat.	Fertilizer.	Spring crop Straw.	Spring crop Paddy.	Fall crop Straw.	Fall crop Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,430	[1] 1,495	....	....	2,925	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,490	1,690	....	....	3,180	0	$5.55	−$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,345	2,567	....	....	4,912	569	9.30	4.92
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,795	2,665	....	....	5,460	667	8.25	8.42
5	None	1,430	1,852	....	....	3,282	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,470	2,405	....	....	4,875	407	11.55	− 1.38
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,705	3,445	....	....	7,150	1,447	23.10	13.07
8	Ammonium sulphate, 300 pounds	4,420	4,095	....	....	8,515	2,097	12.00	40.42
9	Ammonium sulphate, 150 pounds	3,315	3,315	....	....	6,630	1,317	6.00	26.92
10	None	1,885	2,145	....	....	4,030	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops.

1909—SERIES B.

Plat.	Fertilizer.	Yield per acre.					Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.			
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	2,242	[1] 2,015	7,019	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,641	1,625	2,450	3,282	8,998	57	$11.10	−$9.68
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,450	3,867	10,046	1,024	18.60	+ 7.00
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	3,185	4,582	12,007	1,860	16.50	+30.00
5	None	1,267	1,543	2,340	3,575	8,725	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	3,770	4,582	12,544	1,974	23.10	+26.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	3,542	5,070	14,331	3,177	46.20	+33.22
8	Ammonium sulphate, 300 pounds	2,405	2,730	3,575	5,200	13,910	3,080	24.00	+53.00
9	Ammonium sulphate, 150 pounds	1,950	2,285	3,250	4,940	12,425	2,375	12.00	+47.37
10	None	1,379	1,528	2,210	3,055	8,172	....	....	....

1910—SERIES B.

Plat.	Fertilizer.	Spring Straw.	Spring Paddy.	Fall Straw.	Fall Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,722	[1] 1,495	1,560	[1] 1,495	6,272	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,755	1,430	2,145	2,470	7,800	0	$11.10	−$11.10
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,632	2,860	2,405	3,055	10,952	1,073	18.60	+ 8.22
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,405	2,860	2,470	3,445	11,180	1,463	16.50	+ 20.07
5	None	1,755	2,080	2,145	2,762	8,742	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,307	2,892	2,665	3,835	11,699	1,885	23.10	+ 24.02
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium, sulphate, 240 pounds	3,055	3,705	3,250	4,267	14,277	3,130	46.20	+ 32.05
8	Ammonium sulphate, 300 pounds	3,185	3,900	3,055	4,322	14,462	3,380	24.00	+ 60.50
9	Ammonium sulphate, 150 pounds	2,470	2,827	2,967	3,867	12,131	1,852	12.00	+ 34.30
10	None	1,722	[1] 1,690	1,495	[1] 2,015	6,922	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops—Continued.

1911—SERIES B.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Yield per acre. Spring crop. Paddy.	Yield per acre. Fall crop. Straw.	Yield per acre. Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,625	[1] 910	1,755	[1] 2,535	6,825	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,397	1,397	1,787	2,470	7,051	15	$11.10	−$10.78
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,307	2,502	2,242	3,022	10,073	1,672	18.60	+ 23.20
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,502	2,600	2,405	3,445	10,952	2,193	16.50	+ 38.38
5	None	1,332	1,527	1,675	2,437	6,953	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,600	3,055	2,600	3,737	11,992	2,940	23.10	+ 50.40
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,835	4,485	3,347	4,647	16,314	5,280	46.20	+ 85.80
8	Ammonium sulphate, 300 pounds	3,900	4,420	3,185	4,615	16,120	5,183	24.00	+105.57
9	Ammonium sulphate, 150 pounds	2,535	3,152	2,665	3,900	12,252	3,200	12.00	+ 68.00
10	None	1,430	1,820	1,365	1,917	6,532	....	....	....

1912—SERIES B.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Yield per acre. Spring crop. Paddy.	Yield per acre. Fall crop. Straw.	Yield per acre. Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum
1	None	1,430	1,755	....	....	3,185	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,495	1,885	....	....	3,380	0	$5.55	−$5.56
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,730	2,665	....	....	5,495	683	9.30	7.77
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	3,055	2,990	....	....	6,045	1,008	8.25	16.95
5	None	1,560	2,047	....	....	3,607	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	3,120	2,925	....	....	6,045	943	11.55	12.02
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	5,330	4,322	....	....	9,652	2,340	23.10	35.40
8	Ammonium sulphate, 300 pounds	4,680	4,095	....	....	8,775	2,113	12.00	40.82
9	Ammonium sulphate, 150 pounds	4,877	3,120	....	....	7,995	1,138	6.00	22.46
10	None	Lost.	2,145	....	....	....	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Summary of the results of applying fertilizers to seven crops of rice.

Plat.	Fertilizer per crop.	Series A—one application annually. Paddy. Total.	Series A Paddy. Increase.	Series A Total cost of fertilizer.	Series A Total profit or loss.	Series B—two applications annually. Paddy. Total.	Series B Paddy. Increase.	Series B Total cost of fertilizer.	Series B Total profit or loss.	Series B Average profit (+) or loss (—) per acre.
		Pounds.	*Pounds.*			*Pounds.*	*Pounds.*			
1	None	[1] 10,560				[1] 11,567				
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	13,519	26	$22.20	—$21.55	14,559	0	$38.80	—$38.80	—$5.54
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	14,419	926	37.20	— 14.05	19,978	4,908	65.10	57.60	+ 9.39
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	16,134	2,641	33.00	33.02	22,050	6,980	57.75	116.75	+16.69
5	None	13,857				15,971				
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	16,668	3,175	46.20	33.17	23,268	8,198	80.85	124.10	+17.73
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	20,084	6,591	92.40	72.37	29,453	14,383	161.70	197.87	+28.27
8	Ammonium sulphate, 300 pounds	21,352	7,859	48.00	148.47	29,282	14,212	84.00	271.30	+38.76
9	Ammonium sulphate, 150 pounds	19,476	5,983	24.00	125.57	24,091	9,021	42.00	183.52	+26.22
10	None	13,130				14,170				

[1] Injured by cold water flowing directly onto plat. Not included in averages.

The results of these experiments justify the conclusion that for the present at least this soil is in need of nitrogen only. Little or no effects were produced in any case from the use of superphosphate or potassium sulphate, either when applied with or without ammonium sulphate. It is the custom of the rice growers to apply fertilizer, when used at all, to the spring crop only, believing that the more unfavorable weather conditions at that time necessitate the use of stimulants, whereas under the more favorable conditions that prevail during the late summer and early fall fertilizers are less needed. Moreover, it has been considered that the residual effect resulting from the spring application makes itself felt in the fall crop. The above experiments prove conclusively that neither of these opinions is justified. The growth of the fall crop, when more favorable weather prevailed—i. e., higher temperature and longer days—was affected to approximately as great extent by ammonium sulphate as was that of the spring crop. On the whole there appeared no evidence of a cumulative effect even from the heaviest application when made twice annually.

From the data showing the profit and loss it is noteworthy that the application of 300 pounds of ammonium sulphate proved the most economical, either when applied to the spring crop only or to both spring and fall crops, and that in the latter case the profits were very large. So far as these experiments go, they show in addition that the yields can be maintained at a high point and good profit be made under the system now employed, provided the proper fertilizer be used. This is not to be interpreted, however, as being a recommendation of the system now in use, since it has been shown (p. 19) that with the rotation of crops, involving the plowing under of a legume, still greater yields can be obtained. The rotation system is far more rational and permanent and ought to be employed on all rice lands.

It has been found in other countries that the continued application of ammonium sulphate tends to produce acidity in the soil due to the fact that the sulphate ion tends to accumulate in the soil. The occasional application of lime, however, will correct this defect. The highly basic character of Hawaiian soils, on the other hand, particularly the rice soils, justifies the belief that the production of acidity from the use of ammonium sulphate will be far removed in point of time. It is of interest in this connection that the annual application for over 60 years of 300 pounds of ammonium sulphate per acre at Rothamsted to a soil containing considerable amounts of calcium carbonate (probably 100 tons per acre in the first 7 inches) has not produced injurious acidity. The soil on which the above rice experiments were conducted contains a relatively high percentage of lime and magnesia, particularly the latter, but neither of these is present as carbonate in more than very limited amounts. The carbon dioxid content of the soil is low, not more than 0.10 per cent. The iron and aluminum, however, occur largely as hydrates which give to the soil its basic character, and which we may reasonably believe will prevent the accumulation of injurious acidity. It is of further interest to note that the application of lime has been shown to cause a decrease in the yields of rice on this soil.

It would not be safe, however, to recommend ammonium sulphate as the only fertilizer to be applied to the rice lands of the islands generally, since the effects of fertilizers frequently vary widely on different soils. In order to throw further light on this question some experiments have been conducted cooperatively on other rice lands, which resulted in showing that ammonium sulphate produced practically as large increases as a complete fertilizer. At Kailua, for instance, approximately 60 per cent increase in yield was produced both by 150 pounds of ammonium sulphate and by a complete fertilizer containing an equal amount of ammonium sulphate.

As already pointed out, the rice soils, as a rule, are rich in phosphoric acid but contain relatively small amounts of potash. While it is true that rice takes up a large amount of potash only a compara-

tively small part of it enters the grain. In addition, only a comparatively small portion of the straw is really removed from the land, it being the practice to leave about one-half of it on the ground at the time of harvesting, while the remaining portion is used for bedding, etc., a large part of which sooner or later is returned to the soil. Furthermore, whenever manure is accessible the Chinese rice growers cart large quantities of it onto the lands, thus considerably augmenting the potash supply. In view of these facts, then, it is hardly to be supposed that potash fertilizer will be required for many years. In the main, therefore, nitrogen fertilizers only are recommended for Hawaiian rice lands.

In this connection the question of the form of nitrogen best suited to rice naturally arises. Experimental data have been obtained on this subject which permit the drawing of definite conclusions.

THE FORM OF NITROGEN FOR RICE.

One of the most generally accepted teachings in all agricultural literature, based, however, mainly upon experiments with dry-land crops, is that of the high availability of nitrates, it being considered that of all the forms of nitrogen nitrate is the most readily taken up from the soil and used as food by plants. As a result of the prevalence of this view nitrates have been used for rice in America, and indeed sodium nitrate still is recommended at the present time for this crop by some authorities.

It has been known in oriental countries for some time, however, that nitrate is not the most profitable form of nitrogen to apply to rice. Nagaoka,[1] in Japan, demonstrated in 1905 the superiority of ammonium sulphate in a series of pot experiments. He found that while the effects produced by nitrates were variable and discordant the yields were greatly increased in every instance by the use of ammonium sulphate. As a result of his experiments Nagaoka concluded that the value of ammonium sulphate and nitrates stand in the ratio of 100 to 40.

In 1907 Daikuhara and Imaseki[2] also found ammonium sulphate to be much more effective for wet-land rice than either sodium nitrate alone or a combination of the two forms. The value of nitrate was also found to be considerably less when applied in conjunction with organic manures. Likewise it has been shown in several of the Provinces of India that other forms are superior to nitrates. Coleman and Ramachandra Rao,[3] for example, pointed out that organic fertilizers produced a marked stimulation of the growth of rice in Mysore, while niter had but little effect. In 1911 the writer[4] pub-

[1] Bul. Col. Agr., Tokyo Imp. Univ., 6 (1904), pp. 285–334.
[2] Bul. Imp. Cent. Agr. Expt. Sta. Japan, 1 (1907), No. 2, pp. 7–36.
[3] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.
[4] Hawaii Sta. Bul. 24.

lished the results of experiments conducted at the Hawaii station which showed the great superiority of ammonium sulphate over different nitrates.

Notwithstanding these facts some American writers continue to recommend sodium nitrate for rice and to discuss rice soils from the same standpoint as dry lands.

It is not necessary to go into a theoretical discussion of this question at this time further than to state that abundant experimental evidence has already been brought forth in various parts of the world to prove that nitrate is not the only form of nitrogen available to plants. Results obtained at the Hawaii station show that nitrate can hardly be considered to be the principal source of combined nitrogen for many plants when grown in the state of nature. It is known that nitrates are ill suited to assimilation by rice.

To study the practical effects produced on the growth of rice by ammonium sulphate and nitrate nitrogen, respectively, a series of plats was arranged alongside of those used in the experiments discussed above. To one plat ammonium sulphate and to another nitrate of soda was applied before the time of planting. To other plats ammonium sulphate and sodium nitrate were applied in smaller quantities, the same being repeated at intervals of 10 days until six applications had been made. To each plat the total amount of nitrogen applied per acre was the same, and the experiments were repeated for three successive crops. The results follow:

Comparison of ammonium sulphate and sodium nitrate on rice.

Nitrogen applied.	Fall crop, 1909.			Spring crop, 1910.			Fall crop, 1910.		
	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Ammonium sulphate (applied before planting)	3,168	4,603	7,771	3,316	3,564	6,880	2,920	4,010	6,930
Sodium nitrate (applied before planting)	1,881	2,475	4,356	2,029	2,128	4,157	2,227	3,312	5,539
Ammonium sulphate (applied in six applications)	2,475	3,465	5,940	2,772	3,078	5,850	2,722	3,762	6,484
Sodium nitrate (applied in six applications)	2,277	2,623	4,900	1,633	2,079	3,712	1,831	2,427	4,258
Check				1,930	2,178	4,108	2,145	2,762	4,907

From the above yields it is apparent that nitrate of soda produced only slight increases either when applied before transplanting or at intervals during the growth of the crop. Ammonium sulphate, on the other hand, brought about notable increases in every instance, the larger harvests having been obtained from the single application before planting. The repeated applications were made for the purpose of guarding against the loss of nitrate through leaching, but this appeared to have no advantage over the single application.

From pot experiments, where drainage was entirely prevented, the great superiority of ammonium nitrogen over nitrate was again demonstrated. In a series of pot experiments with the use of sterile quartz sand, it was found that where nitrate was the only form of combined nitrogen present rice made very poor growth, whereas ammonium forms seemed to be well suited to its needs. The net result of all these experiments forces the conclusion that nitrate is not a suitable form of nitrogen for rice, but that ammonium compounds are well adapted to its needs.[1]

In the rice-producing countries of the Orient organic manures are the chief source of nitrogen applied to rice soils. It has long been the custom of the Chinese and Japanese to grow some legume between crops for the purpose of enriching the soil. Sometimes the legume is grown on one field, cut, and then distributed over others, so as to gain the benefit of green manuring with as little interruption in the growing of rice as possible. In addition, all sorts of organic nitrogenous substances are freely applied. In Hawaii, on the other hand, almost no rotation is practiced.

From a single experiment conducted by the agronomist of this station, however, it was found that by plowing under a few months' growth of alfalfa just previous to the planting of rice the yield was 50 per cent greater than has ever been obtained on this soil by the application of any commercial fertilizer. In this experiment the alfalfa was grown on one plat, but was cut and applied to another, so that the effects may be attributed to the organic manure directly rather than to a combination of aeration and other effects, the soil being prepared and submerged very soon after making the application. Moreover, the application of different organic nitrogenous fertilizers at various times has always resulted in substantial increases in the yield of rice on this soil. In a series of pot experiments, for example, soy-bean cake was compared with ammonium sulphate. In this experiment nitrogen from each of the two sources was applied at the rate of 70 pounds per acre. The yields obtained were as follows:

Ammonium sulphate versus soy-bean cake as fertilizers for rice.

Treatment of plat.	Straw.	Paddy.	Total.
	Grams.	*Grams.*	*Grams.*
Ammonium sulphate	215	138	353
Soy-bean cake	167	122	289
Check	80	61	141

From the above data it will be seen that soy-bean cake brought about an increase of 100 per cent in the yield, but was considerably inferior in this respect to ammonium sulphate. The reasons for the

[1] The full data with reference to the assimilation of different forms of nitrogen by rice and a more complete bibliography of this subject will be found in Hawaii Sta. Bul. 24.

superiority of ammonium sulphate over organic forms of nitrogen are discussed in greater detail on page 21. In this connection it is of interest to point out that the plant absorbs the principal part of its nitrogen during the early period of its growth;[1] readily available nitrogen therefore is needed when the rice is young, and since the production of available nitrogen from organic forms requires considerable time the application should be made some time in advance of planting, a precaution that was not taken in the above experiments. Through a period of years, however, the total effects would probably become more nearly equal.

AMMONIFICATION AND NITRIFICATION IN RICE SOILS.

The analysis of a number of rice soils taken from the field when wet and analyzed immediately has shown that rice soils contain considerable quantities of ammonia, varying from a few parts up to as much as 50 or 60 parts per million.[2] On the other hand, in the submerged condition nitrate is rarely found in more than mere traces, frequently being entirely absent.

Since good effects are known to follow the use of organic manures, and, furthermore, that ammoniacal nitrogen is especially effective with rice, it becomes a matter of interest to ascertain whether or not ammonia is formed in rice soils at rates sufficient to supply the needs of rice.

Accordingly a series of ammonification experiments were carried out with dried blood as the source of nitrogen, using varying amounts of water, starting in with the air-dry condition and increasing the amounts of water applied up to and beyond the saturation point. One hundred gram portions of soil were placed in tumblers with 2 grams of dried blood added to each. After an incubation period of seven days the ammonia was determined by distilling with magnesium oxid into standard acid. The results obtained were as follows:

Influence of varying amounts of water on the ammonification of dried blood.

Water added.	Nitrogen found as ammonia.		Water added.	Nitrogen found as ammonia.	
	Soil 292.	Soil 461.		Soil 292.	Soil 461.
	Mg.	*Mg.*		*Mg.*	*Mg.*
None (soil air dry)[3]	2.2	3.9	35 cc	131.1	86.8
5 cc	2.2	5.1	40 cc	90.5	85.4
10 cc	37.8	4.3	45 cc	[4] 54.5	71.2
15 cc	164.9	25.5	50 cc	50.7	65.3
20 cc	165.5	41.2	55 cc	48.2	52.4
25 cc	164.6	53.2	65 cc		[4] 15.1
30 cc	140.1	59.0	70 cc		16.1

[1] Hawaii Sta. Bul. 21.

[2] Fraps also showed in 1908 that ammonification takes place much more vigorously in rice soils of Texas than does nitrification (Texas Sta. Bul. 82).

[3] Each soil contained about 5 per cent moisture.

[4] Saturated.

It is here seen that ammonification proceeded at a slow rate only, if at all, until a certain moisture content was reached (about 10 per cent in the case of soil 292 and 15 per cent with that of 461), above which vigorous ammonification took place, which steadily increased up to an approximate two-thirds saturation, then decreased as complete saturation was approached. There was, however, active ammonification in the completely saturated soils. This seems to prove that ammonia is formed in submerged soils and that organic nitrogenous fertilizers will give rise to nitrogen available to rice under conditions that prevail in rice cultures.

As is well known, the formation of ammonia results from the activity of a wide range of soil organisms, bacteria and fungi, some of which are aerobic and some anaerobic. While the above data show that ammonification is more active with moisture supplies below the saturation point, being greatest at approximately two-thirds saturation; nevertheless, the fact that ammonification can take place in saturated soils is of very great importance in the growth of rice. It makes possible the production of available nitrogen in rice soils without the necessity of employing cultural methods that are primarily designed to bring about aerated conditions.

Free oxygen being essential to nitrification, it seems justifiable to conclude that nitrification does not take place to any considerable extent in a submerged soil. In order to throw positive light on the question, however, search was made for nitrates in various submerged soils about Honolulu, but in no instance was more than a few parts per million found. In some laboratory experiments it was further found that practically no nitrification took place in submerged soils.

The process of denitrification, however, is of considerable importance in this connection. As is well known, free nitrogen gas may be one of the products of the decay of organic manures. Likewise, it is also known that certain denitrifying bacteria break down nitrates into nitrites, ammonia, and finally into free nitrogen gas. The conditions under which the denitrifying bacteria function are extremely varied, but the two conditions most favorable for their activity are a source of food supply and a lack of free oxygen. In the rice soils of Hawaii these conditions are abundantly met; the high content of organic matter guarantees a source of food, while supersaturation excludes the air.

As indicated above, the denitrification processes may be conveniently divided into two classes, (1) those causing a liberation of nitrogen from organic materials, and (2) those bringing about a reduction in the nitrates present. The latter of these has been the subject of considerable study at the Hawaii station.

In pot experiments conducted some time ago for the purpose of studying the nutritive value of different forms of nitrogen it was found that in every instance the addition of nitrate to submerged soil resulted in the formation of comparatively large amounts of nitrite within a few days after the time of application. In sand cultures similar effects were observed except where complete sterilization was effected. Furthermore, wherever any considerable amount of nitrite was formed, more than 5 to 6 parts per million, toxic effects were produced, while still greater amounts caused the rice to turn yellow and later to die.

Nitrite, however, was not produced to any considerable extent when organic ammoniacal nitrogen was the only form of combined nitrogen present. A further objection to the use of nitrates as fertilizer for rice is found in the fact, therefore, that nitrates become reduced to nitrites, which are extremely poisonous to rice. Nitrate, then, is unsuited to the nutrition of rice, and in turn may give rise to a substance that is distinctly poisonous.

THE MANAGEMENT OF RICE SOILS.

During the past few years an increasing amount of study has been given to the question of soil management and cultural methods, the rotation of crops, and various methods of soil treatment are coming to be viewed in their relation to this general question. Investigations on special phases of this subject have thrown new light on the important question of soil fertility in general and on that of submerged soils in particular.

In an investigation on the solubility of the island soils[1] some data of interest in this connection were recently obtained. Likewise Coleman and Ramachandra Rao[2] studied the effects on the yield of rice of aerating the soil.

The solubility of substances in submerged soils has been found to be abnormally high, the amounts of the several mineral constituents going into solution in water having been found to be considerably greater than were obtained from any of the dry-land soils of the islands.[1] After the wet soil was allowed to thoroughly dry out, however, the solubility in water was found to be greatly decreased, falling to about the same degree as that of dry lands. Similar data have also been obtained by Coleman and Ramachandra Rao, in Mysore.[2] This seems referable in the main to soil colloids and the formation of soil films in the air-dried state. The overcoming of film pressure and diffusion of dissolved materials upon resubmergence require considerable time, so that the amount of soluble plant

[1] Hawaii Sta. Bul. 30.

[2] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.

food coming into contact with the absorbing root surfaces of rice would be considerably less when planted in a soil that had been thoroughly dried out. Later the mineral constituents would, of course, regain their former state of solubility, but just how much time would be required for the reestablishment of a permanent concentration can not be definitely stated. It seems certain, however, that a lowering of the availability of the mineral constituents would temporarily result from a thorough drying out of the soil.

It is now the practice of the growers, both on the mainland and in Hawaii, to plow their rice lands some weeks before the flooding time, in the latter case immediately following each harvest, so as to permit as much aeration of the soil as possible. As would be expected the aeration prevents nitrification, so that by the time a new crop is planted nitrate has accumulated to a considerable extent. Upon resubmergence the nitrate thus formed becomes partially leached out of the soil and in part converted into poisonous nitrites. The nitrification therefore leads to a direct loss of nitrogen on the one hand and to the formation of a substance toxic to rice on the other. If, however, Hawaiian rice soils are not plowed or cultivated after the water is turned off and the previous crop harvested little or no nitrification sets in. The puddled state of the soil and its compacted condition effectively exclude air. It is only after cultivation and consequent aeration that active nitrification sets in.

Unfortunately no experiments showing the practical effects on the growth of rice as produced by aeration against nonaeration have been conducted at this station. Such experiments, however, have been made in Mysore, the results of which are in complete harmony with the inferences drawn from the nitrogen transformations above referred to. As a result of experiments carried on through two years, Coleman and Ramachandra Rao [1] found that a considerable gain in the yield of rice was obtained by leaving the land in the unplowed condition during the time between crops, the plowing for the new crop being deferred until just before the new crop was planted. By growing a legume between rice crops all needed aeration can be brought about; while the nitrates formed during this period would be absorbed to a large extent by the legume, and in addition free nitrogen from the air would be added to the soil through the growth of the legume. Upon plowing under the legume ammonification will set in, thus furnishing available nitrogen for the next rice crop. The nitrogen requirements of the rice would therefore be met and other beneficial effects that are believed to result from the rotation of crops would be secured. There is little ground

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[1] Loc. cit., p. 9.

to doubt that better conditions would thus be established and greater profits obtained.

In the carrying out of the experiments reported in this bulletin assistance has been rendered by various members of the station staff, to whom thanks are hereby extended.

SUMMARY.

(1) Hawaiian rice soils have originated from basaltic lava, but also contain small amounts of coral limestone.

(2) In texture most of the rice lands are clay loams, and contain approximately equal quantities of fine sand, silt, fine silt, and clay.

(3) In chemical composition these soils are quite similar, with the exception of those from the Waikiki and Kaulaunui districts, the former of which contain abnormal amounts of magnesia, while the latter are highly organic. In general, the nitrogen and phosphoric acid are high, while the potash is low, due largely to the solubility of potash, which is leached from the soil.

(4) From fertilizer experiments carried on through seven crops it was found that the application of 150 pounds per acre of ammonium sulphate produced notable increases in the yield, but 300 pounds per acre proved the more profitable. Potash and phosphoric acid were without effect. The application of ammonium sulphate to both the spring and fall crops yielded considerably more profit than when made to the spring crop only. The residual effects on the fall crop from the spring application are small. The immediate effects obtained from making the application to the fall crop were about the same as those obtained with the spring crop.

(5) A complete fertilizer proved no more effective than ammonium sulphate alone, whereas the application of both ammonium sulphate and potassium sulphate caused a decrease as compared with that obtained from ammonium sulphate alone.

(6) Nitrogenous fertilizers only are recommended for Hawaiian rice soils, and for immediate effects a given amount of nitrogen in the form of ammonium sulphate will produce greater returns than from organic sources. Under no circumstances should nitrates be used as fertilizer for rice.

(7) With nitrate as the only source of combined nitrogen for rice poor growth results. In addition nitrates in submerged soils become reduced to nitrites, which are poisonous to rice. Ammoniacal nitrogen, on the other hand, is well suited to the needs of rice.

(8) Very little nitrification takes place in submerged soil; ammonification, however, goes on, not so vigorously as in aerated soils, but sufficiently to supply the nitrogen needs of rice, provided sufficient organic matter is present in the soil.

(9) A rotation of crops, including the plowing under of a legume, is recommended. It is believed a system can be worked out whereby a legume can be grown between crops and then plowed under, thus gaining the benefits of the rotation and at the same time permitting the growing of two crops of rice annually.

(10) Rice soils should not be plowed and then allowed to lie fallow between crops. Nitrification sets in immediately after aerated conditions are produced and the nitrates thus formed become converted into poisonous nitrites upon resubmergence, or are lost through leaching. When no rotation is practiced it is better to leave the land unplowed until just before planting the next crop.

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HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 33.

THE ORGANIC NITROGEN OF HAWAIIAN SOILS.

BY

W. P. KELLEY,
Chemist,

AND

ALICE R. THOMPSON,
Assistant Chemist.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
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[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 4, 1913.*

SIR: I have the honor to submit herewith, and to recommend for publication as Bulletin 33 of the Hawaii Experiment Station, a paper on The Organic Nitrogen of Hawaiian Soils, by W. P. Kelley, chemist, and Alice R. Thompson, assistant chemist. On account of the great importance of nitrogen to growing plants it is highly desirable to know more about the nature of the nitrogenous substances in soils. In the research which served as a basis for the present bulletin an attempt was made to determine, so far as possible, the forms in which nitrogen occurs in the soils, and the relative percentages of the various nitrogenous products. These studies furnish an important contribution to the subject, which will later be supplemented by a study of the products of various vegetable proteids when acted upon by bacteria.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

CONTENTS.

THE ORGANIC NITROGEN OF HAWAIIAN SOILS.

INTRODUCTION.

The greater part of soil nitrogen may reasonably be assumed to have been bound up at one time or another in protein combinations, since the nitrogen in the main has been derived from vegetable sources. Limited amounts of other nitrogen bodies, such as alkaloids, etc., also find their way into soils, but the nitrogen from such compounds could hardly be expected to amount to more than a small percentage of the total nitrogen present. The chemistry of soil nitrogen and the changes that it undergoes, therefore, must be largely those of plant proteins, brought about under complex and indeed extremely variable conditions. A great host of organisms inhabiting soils are associated with the transformations of the organic nitrogen bodies, and the conditions and environment in which the organisms function not only materially alter the rates of their action but also determine largely what the end products shall be. The presence of various chemical substances, both organic and inorganic, the acidity or alkalinity, and the degree of porosity of the soil, all exert important influences on the activity of soil organisms.

During the past few years considerable study has been devoted to the nitrogen compounds of the soil. In 1905–6, Shorey,[1] while chemist at this station, applied to a coffee soil from the island of Hawaii the methods formerly used in the study of protein, and thus determined the amounts of basic, nonbasic, ammonia nitrogen, etc., split off by means of boiling acids. In connection with his studies a pyridin derivative, picolin carboxylic acid, was isolated and identified, this being the first definite organic nitrogen compound to be isolated from a soil. Recently a number of other studies on soil nitrogen have been reported.[2]

The researches previously made on this subject naturally divide themselves into two classes, as indicated by the work of Shorey. First, a study of the individual compounds that occur in natural soils; second, a study of the products formed by acid hydrolysis. The extensive researches of Schreiner, Shorey,[3] and their associates

[1] Hawaii Sta. Rpt. 1906, pp. 37–59.

[2] Jodidi, Michigan Sta. Tech. Bul. 4 (1909); Iowa Sta. Research Buls. 1 and 3 (1911); Robinson, Michigan Sta. Tech. Bul. 7 (1911); Lathrop and Brown, Pennsylvania Sta. Rpt. 1910, pp. 118–129; Jour. Indus. and Engin. Chem., 3 (1911), pp. 657–660.

[3] U. S. Dept. Agr., Bur. Soils Buls. 47, 53, 74, 80, 87, 88, 89.

in the Bureau of Soils, conducted mainly with reference to the individual compounds actually occurring in soils, have brought to light much important information. Likewise the work of Jodidi,[1] Robinson,[1] and others, is of interest in its bearing on the hydrolytic products split off by means of acids. From the investigations on the hydrolytic products it has been shown that soils vary considerably in regard to the relative percentages of the several groups of nitrogen compounds split off in the treatment, and although only a comparatively small number of soils have been studied, these, in the main, have been found to yield the greatest amount of nitrogen in the form of monamino acids. Approximately 25 per cent of the nitrogen split off was in the form of amids, while the diamino nitrogen has been found in still smaller amounts, usually not more than 10 per cent of the total nitrogen dissolved.

It is not necessary to discuss in detail the studies previously made on this subject. It is sufficient to say that too much importance can hardly be given to the nitrogen of soils. The element lies at the very foundation of plant growth. The use of nitrogenous fertilizers has assumed enormous proportions throughout the world. In Hawaii extremely heavy applications have been made for many years, and the tendency during the past few years has been toward even greater applications. Many of the soils, however, contain a relatively high percentage of nitrogen. In some instances, even where very heavy applications of nitrogenous fertilizers are made, the soils contain 0.5 per cent or more of nitrogen.

Investigations on nitrification and ammonification in different Hawaiian soils have been under way in this laboratory for some time, and the results obtained have been of such nature as to emphasize the need for a better understanding of the chemical nature of the nitrogen bodies contained in these soils. Studies have accordingly been undertaken on this subject, employing the process of acid hydrolysis. In this work the nitrogen as a whole has been studied by subjecting to hydrolysis weighed portions of the original soils. On account of the great importance generally attached to humus, and the limited state of knowledge concerning the chemistry of this material, some study was devoted to the alkali soluble nitrogen bodies.

Since the substances to be investigated originally came from a number of plants, the protein of which has not been sufficiently studied, and have probably already undergone much change through the action of bacteria, there are no definitely understood materials to start with. The hydrolytic products obtained, therefore, leave much room for speculation. Just how far the cleavages had already gone in the soils previous to treatment remains a matter for much further work before definite conclusions can be drawn.

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[1] Loc. cit.

THE NITROGEN OF HAWAIIAN SOILS.

The soils used in this investigation belong to the laterite class common to the islands. Sample No. 379 is a silty loam, containing considerable amounts of organic matter. It was taken from old pasture land in the Kula district of Maui, where semiarid conditions prevail.

Sample No. 428 is a highly organic sandy soil from Glenwood, in the Hilo district of Hawaii, where the rainfall is very heavy, but good drainage prevails. The sample came from land recently cleared of a tropical jungle and may be considered virgin fern forest soil.

Sample No. 447 is a silty loam from the Kunia district of Oahu, where semiarid conditions prevail, and is now being used for pineapples, but formerly was devoted to pasture for many years.

Sample No. 292 taken from the lands previously used for rice experiments by this station, represents a loam soil containing considerable gravel, and has been devoted to aquatic agriculture for many years.

Samples Nos. 343 and 345 are each rice soils of a silty character, having been taken from the Kaneohe district on the windward side of Oahu. These lands have been devoted to continuous rice culture for from 30 to 40 years.

Sample No. 347 is a highly humus soil, taken from the Punuluu district of Oahu, and likewise has been continuously cultivated in rice for thirty or more years.

Samples Nos. 405 and 406 are silty soils taken from the Kalihi district of Oahu, and have been devoted to aquatic agriculture for many years, the former to rice and the latter to taro.

NITRATE AND AMMONIA.

It was deemed of interest to determine the amounts of nitrate and ammonia present in the soil preliminary to a study of the organic constituents. Nitrate was determined from water solutions, by the use of the phenol-disulphonic acid method, while the ammonia was determined by the direct distillation of separate portions of the soil with magnesium oxid. The results calculated to the water-free basis are given in the following table:

Total nitrate and ammonia nitrogen in Hawaiian soils.

Soil No.	Total nitrogen, per cent.	Nitrate nitrogen.		Ammonia nitrogen.	
		Parts per million.	Per cent of total nitrogen.	Parts per million.	Per cent of total nitrogen.
379	0.592	10	0.169	10	0.169
428	.770	45	.584	220	2.857
447	.354	62	1.751	10	.282
292	.122	4	.328	10	.819
343	.220	0	.000	22	1.000
345	.218	0	.000	32	1.468
347	1.241	70	.564	130	1.048
405	.195	1	.050	50	2.564
406	.456	15	.329	60	1.316

The above data show that the soils of Hawaii are similar to soils elsewhere in that the nitrogen present as nitrate and ammonia constitutes but a small percentage of the total nitrogen. In contrast to ordinary soils the ammonia content in most instances was considerably greater than the nitrate.[1] The nitrogen of these soils exists, therefore, very largely in organic combinations.

ORGANIC NITROGEN.

When a study is made of the organic nitrogen greater difficulties are at once encountered. The isolation of the various individual nitrogen compounds occurring in soils must necessarily be a tedious undertaking. It has been shown, however, that by means of the hydrolytic method as used in the study of protein chemistry, some conception can be obtained regarding the make-up of the nitrogen bodies of the soil. By the use of this method the amounts of nitrogen split off in the form of amids, diamino, and monamino acids are relatively easily determined.

Partly on account of the readiness with which these determinations can be made, and partly for the reason that the soil nitrogen may reasonably be supposed to have originated largely from vegetable proteins, many of which are known to be susceptible to complete hydrolysis, use has been made of the process of hydrolysis in this work. In addition it seems probable that the action of bacteria on soil nitrogen is progressive and of a hydrolytic nature.

On the other hand, the work of Osborne[2] and others show that the hydrolytic products vary widely with the different proteins and indicate that the results obtained in soil studies by the use of hydrolytic agents must be of the most general nature. Nevertheless, it is believed that much valuable information can be obtained in this way.

In the work reported in this bulletin the Osborne-Harris[3] modification of the Hausmann[4] method, as outlined by Jodidi[5] in his studies on Iowa soils, has been used. The hydrolysis was conducted by heating to boiling under a reflux condenser for 10 hours 50-gram portions of the air-dried soils with 750 cubic centimeters strong hydrochloric acid, filtering, and making the filtrate to 1 liter. Aliquots of the solution thus obtained were used for the determination of the amid, basic, and nonbasic nitrogen. The amid nitrogen, determined as ammonia by the direct distillation of the solutions after making alkaline with magnesium oxid, would also contain the ammonia orig-

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[1] The occurrence of large quantities of ammonium compounds is a phenomenon common to many Hawaiian soils.

[2] The Vegetable Proteins. London and New York, 1909.

[3] Jour. Amer. Chem. Soc., 25 (1903), p. 323.

[4] Ztschr. Physiol. Chem., 27 (1899), p. 95.

[5] Iowa Sta. Research Bul. 1 (1911).

inally present in the soil. This was deducted from the amounts found.

The basic nitrogen was determined by precipitation with phosphotungstic acid in water solutions obtained by filtering the residue left after the distillation with magnesium oxid. As shown by previous investigators,[1] the nitrogen thus obtained in this precipitate occurs largely in the form of diamino acids. Purins, alkaloids, etc., may also be precipitated by phosphotungstic acid, and, therefore, if present, would be contained in this group. The nonbasic nitrogen was determined by subtracting the sum of the other two groups from the total nitrogen dissolved. While this group is now referred to by some investigators as monamino acids, Jodidi and Robinson have each brought forth evidence that it is not made up wholly of monamino acids. Just what other bodies occur in this group is not yet known. The results obtained, calculated as in all other cases in this bulletin on the water-free basis, are given in the following table:

Organic nitrogen of Hawaiian soils.

[Soluble in hydrochloric acid.]

Soil No.	Per cent of total nitrogen.	Per cent of the soil.				Per cent of nitrogen in solution.		
		Amid.	Basic nitrogen.	Nonbasic nitrogen.	Total.	Amid.	Basic.	Nonbasic.
379	71.96	0.095	0.030	0.300	0.426	22.30	7.04	70.42
428	72.59	.141	.028	.368	.559	24.79	5.01	66.27
447	67.51	.074	.033	.131	.239	30.96	13.81	54.82
292	91.80	.024	.012	.075	.112	21.43	10.71	66.96
343	90.91	.054	.020	.124	.200	27.00	10.00	62.00
345	88.52	.042	.017	.131	.193	21.76	8.81	67.88
347	80.42	.225	.097	.663	.998	22.55	9.72	66.43
405	84.62	.042	.019	.099	.165	25.45	11.51	60.00
406	91.22	.079	.055	.276	.416	18.99	13.22	66.35
Average						23.91	9.98	64.57

The above table shows that there is considerable variation in the amounts of soluble nitrogen in different soils. In soil No. 447 only 67.51 per cent of the total nitrogen was dissolved, while No. 292 yielded 91.80 per cent. Concerning the insoluble nitrogen very little is known.

AMIDS.

Upon distilling the solutions after making them alkaline with magnesium oxid approximately 25 per cent of the nitrogen in solution was obtained in the form of ammonia, here referred to as amid nitrogen, and all the soils studied, with the exception of Nos. 447, 343, and 406, yielded approximately the same relative amounts of nitrogen as ammonia. It is of interest to note that the amids constitute a

[1] Jodidi, loc. cit.; Robinson, loc. cit.

considerably higher percentage of the nitrogen of soils than are reported to occur in vegetable proteins. For example, the investigations of Osborne show that, on an average, the seed proteins contained 11.6 per cent of their nitrogen as amids. In a few cases, however, as, for example, gliadin from wheat and rye and hordein from barley, the amids comprised more than 20 per cent of the total nitrogen. On the other hand, a large number of proteins studied were found to contain considerably less than 10 per cent of their nitrogen in amid form.

A direct comparison of the amid nitrogen of the above soils with that found in soils elsewhere is possible in a few cases only, for the reason that the strengths of the acid, and the lengths of the time of digestion, used in the investigations on this subject vary so greatly. With the results obtained by Jodidi, however, our data are comparable, and from his work on Michigan peat and Iowa soils the amounts of amid nitrogen found were approximately the same as those found in Hawaiian soils.

BASIC NITROGEN.

The percentage of nitrogen precipitated by phosphotungstic acid was found to vary considerably in the different soils studied, but on the average to be similar to the amounts reported by Jodidi. In these studies no attempt was made to prove the nature of these nitrogen compounds, but from the work of others it seems permissible to consider them as being composed principally of diamino acids. It is noteworthy that the percentages of basic nitrogen in soils fall far below the percentages found in the majority of vegetable proteins. With the exception of glutenin from wheat, gliadin from wheat and rye, hordein from barley, and zein from maize, the basic nitrogen comprises more than 20 per cent of the total nitrogen in the vegetable proteins previously studied, and in a number of instances even more than 30 per cent of it. The basic nitrogen compounds of Hawaiian soils comprise only about 10 per cent of the total nitrogen.

Since the principal diamino acids that occur in vegetable proteins are arginin, histidin, and lysin, each of which can be precipitated from dilute solutions by phosphotungstic acid, it may be assumed that these compounds contain the principal diamino nitrogen split off in the hydrolysis of soil organic matter. The amounts found vary considerably. This may be accounted for in part by the fact that the phosphotungstic acid method, in order to give reliable results, must be conducted under as definite conditions as possible. In view of the presence in the solution of various inorganic salts dissolved in the hydrochloric acid digestion, it is hardly to be supposed that the conditions of this precipitate were indentical with the different soils. The precipitate is slightly soluble in the solutions employed, and

at the same time somewhat difficult to separate entirely from the nonbasic nitrogen in the solution. For these reasons some variation in the results is to be expected.

NONBASIC NITROGEN.

The percentages of nonbasic nitrogen, with the exception of that from soil No. 447, were found to be remarkably similar in every instance, amounting to about two-thirds of the nitrogen dissolved by boiling hydrochloric acid. In this respect the soluble nitrogen of soils is quite similar to that of vegetable proteins. The nonbasic nitrogen of soils is looked upon as being composed largely, but not entirely, of monamino acids, and probably such as are obtained in the hydrolysis of protein. Robinson,[1] for example, isolated leucin and isoleucin from hydrochloric-acid solutions of Michigan peat. Doubtless other monamino acids occur in the solutions. It is claimed, however, that a considerable portion of the nonbasic nitrogen of soils occurs in forms other than as monamino acids. Robinson, by the use of the Van Slyke nitrous acid method for the determination of monamino acids, found considerably less monamino acid in solution than was necessary to account for the nonbasic group, while Jodidi arrived at similar conclusions by the use of the formaldehyde titration method. Osborne,[2] has presented data supporting the idea that the nonbasic nitrogen obtained from vegetable proteins actually occurred as monamino acids. As yet no explanation of this difference between the nitrogen of soils and that of vegetable proteins has been proposed. The soluble nonbasic nitrogen in Hawaiian soils approximates the amounts found in soils elsewhere.

EFFECTS OF AERATION ON SOIL NITROGEN.

Some references have already been made to the fact that a wide range in the degree of aeration prevails in different Hawaiian soils, and that some of the soils studied in this investigation represent extremes in this respect. By reference to the previous description of the soils it is seen that soils Nos. 379, 428, and 447 represent aerated soils, 379 and 447 particularly so, since they are taken from well aerated land in sections where semiarid conditions have prevailed for many years. The remaining soils studied represent anaerobic conditions, since they have been used in aquatic agriculture a large part of the time for many years. So far as known no nitrogenous fertilizers of any sort have been applied to any of these soils.

It is generally held that the production of ammonia from organic nitrogen is necessary before its nitrification can take place, and that ammonia can be formed by a wide range of soil organisms. Some of these

[1] Loc. cit.

[2] The Vegetable Proteins. London and New York, 1909.

are aerobic, some anaerobic, while still others are able to act under either of the two conditions. It has also been shown at this station [1] that ammonification actually takes place in soils during the time of submergence. The relative amounts of amid, basic, and nonbasic nitrogen occurring in soils which had long been subjected to extreme conditions of aeration were determined to obtain evidence as to the nature of the chemical changes induced by the organisms when operating under the two sets of conditions.

By again referring to the table (p. 9) it will be seen that the percentages of the total nitrogen dissolved by hydrochloric acid were greater in every instance in the soils long subjected to anaerobic conditions. On an average 70.69 per cent of the total nitrogen was dissolved from aerated soils, while 87.93 per cent was rendered soluble in the unaerated soils. These data indicate that the putrefactive decay, which evidently predominates in submerged soils, leaves the nitrogen in a form more easily dissolved by hydrochloric acid than the process of eremacausis, that takes place under aerated conditions.

The relative amounts of the different groups obtained from the soils representing the two classes of conditions, however, were found to be quite similar in most instances. The table showing the nitrate and ammonia present (p. 7) indicates that with the exception of soils Nos. 347 and 406, those representing unaerated conditions contained next to no nitrate. The nitrate found in the remaining unaerated soils was formed almost entirely during the time of drying out in the laboratory. These samples were taken from the field in a wet state and then contained practically no nitrate. In fact, nitrification scarcely takes place at all in submerged Hawaiian soils. The data, therefore, fail to give any indication of a fundamental difference in the nature of the hydrolyses which take place under aerobic and anaerobic conditions.

HUMUS NITROGEN.

The alkali soluble organic matter of soils, usually known as humus, is generally considered to be of special importance. Only a part of the organic matter present in soils occurs as humus, and generally very little attention is paid to the remaining. For this reason some study has been given to the nitrogen bodies contained in it. In this investigation it was hoped to learn something regarding the chemical make-up of these bodies by determining the amounts of the different nitrogen groups actually present. Some light was also sought on the question whether or not the alkali soluble nitrogen bodies are really different from the organic nitrogen of soils as a whole. The soils used

[1] Hawaii Sta. Bul. 31.

in this phase of the work were the same as those employed in the studies reported in the preceding pages.

NITROGEN DISSOLVED IN THE PRELIMINARY 1 PER CENT HYDROCHLORIC ACID EXTRACTION.

Calcium and magnesium are generally combined to some extent with the humus bodies in such a way as to render the organic matter less soluble in dilute alkalis. In order to break up such combinations the soils are treated with 1 per cent hydrochloric acid until no further amounts of calcium and magnesium are dissolved. It is customary in humus determinations, then, to dissolve the humus bodies in 4 per cent ammonia solution. In brief investigations [1] carried on in this laboratory it was observed that the dilute hydrochloric acid extracts obtained in the preliminary treatment contained considerable organic matter. In one instance the solution was darkly colored and found to contain a notable amount of organic matter. Usually such solutions are discarded. It has been shown, however, that considerable amounts of nitrogen are dissolved from certain soils [2] in this preliminary acid extraction. In the work here reported the soils were first extracted with 1 per cent hydrochloric acid, then filtered and washed to neutrality. The solutions thus obtained should contain the ammonia originally present. The solutions were evaporated to a small volume and the nitrogen in them was determined by the Kjeldahl method, with the following results:

Nitrogen of soils soluble in cold 1 per cent hydrochloric acid.

Soil No.	Per cent of soil.	Per cent of total nitrogen.	Soil No.	Per cent of soil.	Per cent of total nitrogen.
379	0.019	3.21	345	0.007	3.21
428	.041	5.33	347	.029	2.34
447	.012	3.39	405	.009	4.61
292	.004	3.28	406	.012	2.63
343	.004	1.82			

By comparing these data with those given in the first table it will be seen that in every instance the soils contained only about one-half as much ammonia nitrogen as was dissolved by 1 per cent hydrochloric acid, while in a number of instances still greater amounts of nitrogen were dissolved. Some organic nitrogen, therefore, was thus dissolved, although the amounts were small.

In preparing the humus solutions for studies on the nitrogen bodies a 3 per cent solution of sodium hydrate was employed. With Hawaiian soils sodium hydrate solution has a special advantage of

[1] Hawaii Sta. Press Bul. 33.

[2] Rimbach, Jour. Amer. Chem. Soc., 22 (1900), p. 695.

causing much less deflocculation of the clay, so that by ordinary filtration the solutions can be freed from all but traces of clay. Forty grams, after extracting with dilute hydrochloric acid, were treated with 2,000 cubic centimeters of 3 per cent sodium hydrate solution for a period of two days, with occasional shaking during the first day. The solutions were siphoned off and aliquot portions used in the studies.

SEPARATION OF DIFFERENT FORMS OF NITROGEN IN HUMUS.

A part of the humus can be precipitated from the alkali solutions by acids, and this method has been used for obtaining so-called pure humus. The amounts precipitated, however, vary with the amount of acid used. Shorey [1] has shown that after filtering out the precipitate obtained by acidifying the humus solution a still further precipitate can be obtained by carefully neutralizing the filtrate, and that of the precipitates thus obtained each contains nitrogen. The humus extract made with a 2 per cent sodium hydrate solution was found to contain 0.0399 gram nitrogen per 100 cubic centimeters of solution. The hydrochloric acid filtrate he found to contain 0.0251 gram of nitrogen per 100 cubic centimeters of the original solution, and on neutralizing this filtrate with caustic soda the precipitate formed was found to contain 0.0168 gram of nitrogen.

In the work here reported hydrochloric acid was carefully added to 1,000 cubic centimeter portions of the humus solution (corresponding to 20 grams of soil) to apparent neutrality to litmus paper, then 20 cubic centimeters of 1 per cent hydrochloric acid was added, the precipitate formed was collected on a filter and washed. In this way the humus matter was roughly separated into two parts. The precipitates thus obtained were afterwards subjected to acid hydrolysis by boiling with 400 cubic centimeters strong hydrochloric acid for a period of 10 hours, and then filtering and washing the residue. The amid and basic nitrogen contained in the original humus solutions, in the filtrates obtained from precipitating the solutions with dilute hydrochloric acid, and in those obtained upon hydrolyzing the humus precipitates, have been determined.

The following table shows the total nitrogen contained in the original humus solutions, and that in the portions obtained by the various separations:

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[1] Hawaii Sta. Rpt. 1906.

The nitrogen of humus.

Soil No.	Total nitrogen in soil. Per cent of soil.	Humus nitrogen precipitated by HCl.		Humus nitrogen not precipitated by HCl. (c). Per cent of soil.	Total humus nitrogen by addition (a+b+c). Per cent of soil.	Total humus nitrogen determined directly. Per cent of soil.	Humus nitrogen in per cent of soil nitrogen.	Humus nitrogen not precipitated by HCl. Per cent of total humus nitrogen.	Humus nitrogen precipitated by HCl.	
		Hydrolyzable (a). Per cent of soil.	Non-hydrolyzable (b). Per cent of soil.						Hydrolyzable. Per cent of humus nitrogen.	Non-hydrolyzable. Per cent of humus nitrogen.
347	1.241	0.362	0.125	0.315	0.802	0.774	62.37	39.28	45.14	15.59
428	.770	.289	.051	.247	.587	.590	76.62	42.08	49.23	8.69
379	.592	.270	.041	.129	.440	.439	74.16	29.32	61.36	9.32
406	.456	.100	.027	.117	.244	.226	49.56	47.96	40.98	11.06
447	.354	.094	.026	.105	.225	.215	60.79	46.67	41.78	11.56
345	.218	.066	.019	.070	.155	.147	67.43	45.16	42.58	12.26
343	.220	.061	.012	.069	.142	.127	57.73	48.59	42.96	8.45
405	.195	.044	.012	.067	.123	.123	63.08	54.47	35.77	9.76
292	.122	.031	.012	.015	.058	.058	67.54	25.86	53.45	20.69
Average							64.36	42.15	45.92	11.93

The above data show that the humus nitrogen varied with different soils, but averaged 64.36 per cent of the total nitrogen. In every instance, except two, more than one-half of the nitrogen was dissolved by dilute alkali, while in two instances practically three-fourths of it was thus extracted. The bodies precipitated with dilute hydrochloric acid also contained nitrogen in varying amounts. The nitrogen bodies precipitated by hydrochloric acid upon subsequent hydrolysis yielded by far the greater portion of their nitrogen to the solutions, the insoluble residues having been found to contain 11.93 per cent of the humus nitrogen. By these methods, therefore, the nitrogen of soils can be separated into fractional parts.

AMID NITROGEN.

The amid nitrogen in the original humus solutions was first determined by evaporating the solutions on the water bath, after slightly acidifying with hydrochloric acid, then making alkaline with magnesium oxid and distilling. The relatively high percentages of ammonia thus obtained suggested that some hydrolysis had taken place during the time of the evaporation on the water bath, possibly through the action of the hydrochloric acid present. In order to eliminate this possibility, separate portions were distilled directly with magnesium oxid, after having been slightly acidified with hydrochloric acid. In like manner the solutions, obtained after filtering out the humus matter precipitated by hydrochloric acid, were distilled with magnesium oxid, and also the solutions obtained

by hydrolyzing the humus precipitate. The results are shown in the following table:

Amid nitrogen in humus.

Soil No.	Solutions slightly acidified and evaporated before distillation. Per cent of soil.	Solutions slightly acidified. No evaporation. Per cent of soil.	Not precipitated by HCl. (a). Per cent of soil.	Precipitated by HCl. (b). Per cent of soil.	Total. a+b.	Total. Per cent of total soil nitrogen.	Total. Per cent of humus nitrogen.
317	0.100	0.087	0.095	0.073	0.168	13.54	21.70
428	.073	.073	.074	.056	.130	16.88	22.03
379	.059	.052	.056	.061	.117	19.76	26.65
406	.039	.028	.040	.020	.060	13.15	26.55
447	.033	.026	.031	.027	.058	16.38	26.98
345	.025	.018	.022	.016	.038	17.43	25.85
343	.020	.020	.025	.018	.043	19.54	33.86
405	.026	.017	.014	.023	.037	18.97	42.53
292	.009	.012	.008	.011	.019	15.57	32.76
Average						16.80	28.77

The relatively high percentages of amid nitrogen obtained from the original humus solutions is noteworthy, as is also the fact that the nitrogen bodies not precipitated by hydrochloric acid contained practically all of the amid nitrogen existing as such in the humus solution. On an average, the hydrochloric acid precipitate yielded upon hydrolysis practically the same amounts of amid nitrogen as were contained in the original humus solutions. The total amid nitrogen contained in the humus, when calculated to the percentages of the total soil nitrogen, presents some variation, and on the average amounted to 16.80 per cent of the total soil nitrogen. When such data were calculated to the basis of the humus nitrogen it was found that the relative amounts of amid nitrogen contained increased with a decrease in the humus nitrogen. In other words, relatively greater amounts of amids occurred in soils which contain a low percentage of humus nitrogen. This may be purely a coincidence, but is probably due to the fact that either in the preparation of the humus solution, or in the process of determining the amid nitrogen in it, a certain amount of hydrolysis took place which would tend to markedly increase the relative amounts of amid obtained from those humus solutions containing the smallest amounts of nitrogen. On an average, 28.77 per cent of the humus nitrogen was found to be present as amids. It will be recalled that the amid nitrogen obtained upon hydrolyzing the soils as a whole amounted to considerably smaller percentages of the nitrogen dissolved.

BASIC NITROGEN.

The basic nitrogen bodies in humus were determined by the phosphotungstic acid method, as already outlined. The results are recorded in the following table:

Basic nitrogen in humus.

Soil No.	In the original humus solution. Per cent of soil.	Not precipitated by HCl. (a). Per cent of soil.	Precipitated by HCl. (b). Per cent of soil.	Total.		
				a+b. Per cent of soil.	Per cent of total soil nitrogen.	Per cent of total humus nitrogen.
347	0.028	0.024	0.010	0.034	2.74	4.39
428	.027	.025	.010	.035	4.81	5.93
379	.017	.021	.007	.028	4.73	6.38
406	.015	.014	.009	.023	5.05	10.18
447	.021	.019	.006	.025	7.06	11.63
345	[1] .003	.017	.017	.034	15.59	23.13
343	[1] .004	.017	.008	.025	11.36	19.68
405	.011	.009	.008	.017	8.71	19.54
292	.014	.009	.017	.026	21.31	44.83

[1] There is apparently some error in these determinations.

It was found that the basic nitrogen amounted to practically the same percentages when determined directly from the original humus solutions as were present in the filtrates from the hydrochloric acid precipitate. The amounts of basic nitrogen split off in the hydrolysis of the precipitates were relatively smaller, as compared with the amid nitrogen, than were obtained in the filtrates. The total basic nitrogen, calculated to percentages of the total soil nitrogen, increased with a decrease in the amount of nitrogen in the soil, and when calculated to percentages of the total humus nitrogen the same relationships are even more marked. Soil No. 347, containing 0.77 per cent humus nitrogen, yielded only 4.39 per cent of it as basic nitrogen, while soil No. 292, containing 0.058 per cent humus nitrogen, yielded 44.83 per cent of it as basic nitrogen.

In view of the analytical error involved in the determination of the basic nitrogen, it is unsafe to generalize concerning the relatively great increases in the basic nitrogen of humus in passing from soils with large to soils of smaller humus nitrogen content. It seems probable, however, that hydrolysis took place during the alkali extraction process.

NONBASIC NITROGEN.

It is obviously not permissible to consider the difference between the total nitrogen in humus and the amounts of amid and basic nitrogen that occur in the original humus solutions as nonbasic nitrogen, for the reason that these solutions can not be considered as having been completely hydrolyzed. It is well known, for example, that various proteins are quite soluble in alkalis without the proteins undergoing any particular hydrolysis, as they can be precipitated, in a more or less unaltered condition, from such solutions by the addition of acid. On the other hand, the nitrogen compounds in the filtrates obtained from the humus precipitated by dilute hydrochloric

acid, and also those split off in the hydrolysis of the humus precipitate, may reasonably be considered as being made up of amid, basic, and nonbasic nitrogen compounds. We have, therefore, calculated the amounts of nonbasic nitrogen in these portions of humus. The results are shown in the following table:

Nonbasic nitrogen in humus.

Soil No.	In filtrates from HCl precipitates.			In hydrolyzed humus precipitates.			Total.	
	Per cent of soil.	Per cent of nitrogen in filtrate.	Per cent of humus nitrogen.	Per cent of soil.	Per cent of nitrogen in solution.	Per cent of humus nitrogen.	Per cent of soil.	Per cent of humus nitrogen.
347	0.196	62.22	25.32	0.249	68.78	32.17	0.445	57.49
428	.148	59.92	25.08	.213	73.70	36.10	.361	61.18
379	.052	40.31	11.84	.203	75.18	46.24	.255	58.08
406	.063	53.84	27.87	.071	71.00	30.97	.134	58.84
447	.055	52.38	25.58	.061	64.89	28.36	.116	53.94
345	.031	44.28	21.09	.033	50.00	22.45	.064	43.54
343	.027	39.13	21.26	.035	57.37	27.56	.062	48.82
405	.046	68.65	37.39	.011	[1] 25.00	[1] 8.78	.057	45.17
292	....	....	....	.003	[1] 9.67	[1] 5.18	....	....
Average	....	52.59	25.05	....	64.84	31.98	....	53.38

[1] Not included in averages.

These data show the relatively large amounts of nonbasic nitrogen contained in humus. On the average about 25 per cent of the humus nitrogen occurred in the original humus solutions as nonbasic nitrogen compounds, or 52.59 per cent when calculated to the percentage of humus nitrogen soluble in dilute hydrochloric acid. The solutions obtained upon hydrolyzing the humus precipitated by dilute hydrochloric acid yielded a still greater amount of nonbasic nitrogen. On an average 64.84 per cent of this nitrogen occurred as nonbasic, which, when calculated to percentages of the total humus nitrogen, amounts to 31.98 per cent. By adding the nonbasic nitrogen in these two portions of humus it is found that 53.38 per cent of the humus nitrogen is made up of nonbasic nitrogen compounds. By referring to the data previously presented (p. 9) it will be seen that the relative amounts of nonbasic nitrogen in humus are somewhat less than the amounts of nonbasic nitrogen obtained in the hydrolysis of the soil as a whole.

Considering the different groups of nitrogen compounds as obtained from the different portions of humus, the preceding data show that the humus contained slightly less amid, basic, and nonbasic nitrogen than were split off upon hydrolyzing the soil nitrogen as a whole, but, on the other hand, the humus nitrogen bodies as such are made up of relatively more amid and basic nitrogen than the soil nitrogen as a whole. In other words, the nitrogen of soils soluble in 3 per cent sodium hydrate is bound up in bodies differing somewhat from the

nitrogen bodies not soluble in the solvent. In view of the relatively large amounts of amid, basic, and nonbasic nitrogen contained in the original humus solutions, it is believed that considerable hydrolysis of the proteins occurring in soils has taken place through the action of bacteria, and that the humus nitrogen is probably of more immediate value as a source of available nitrogen than is the nonhumus nitrogen. It seems justifiable to believe, therefore, that the humification process is really one of importance in soils as a step toward the production of available nitrogen compounds.

DETERMINATION OF HUMUS NITROGEN.

In view of the large amounts of amid nitrogen obtained in the original humus solutions some study was directed to the question of methods for the determination of total humus nitrogen. The data previously submitted, showing the total humus nitrogen, were obtained by first evaporating the solutions after acidification with hydrochloric acid, then subjecting the residues to nitrogen determination by the use of the regular Kjeldahl method. The determination of humus nitrogen is frequently made from ammonia solutions of humus after expelling the free and combined ammonia present by distilling the magnesium oxid.[1] But on account of the relatively large amounts of amid nitrogen found in the sodium hydrate solutions, which, if present in corresponding amounts in ammonia solutions of humus, would be lost in the magnesium oxid distillation, there is brought into comparison the nitrogen of these soils as found in both the sodium hydrate and ammonia solutions. The results are recorded in the following table:

Total humus nitrogen by different methods.

Soil No.	Amid nitrogen in NaOH solution. Per cent of soil.	Total humus nitrogen in NaOH solution. Per cent of soil.	Total humus nitrogen in ammonia solution. Per cent of soil	Nitrogen absorbed from ammonia solutions. Per cent of soil.	Soil No.	Amid nitrogen in NaOH solution. Per cent of soil.	Total humus nitrogen in NaOH solution. Per cent of soil.	Total humus nitrogen in ammonia solution. Per cent of soil.	Nitrogen absorbed from ammonia solutions. Per cent of soil.
347	0.100	0.774	0.657	0.502	345	0.025	0.147	0.140	0.085
428	.073	.590	.609	.753	343	.020	.127	.117	.175
379	.059	.439	.284	.523	405	.026	.087	.099	.139
406	.039	.226	.179	.264	292	.009	.058	.067	.072
447	.033	.215	.218	.147					

In some instances much higher percentages of nitrogen were found in the sodium hydrate solutions than in the ammonia solutions, and in some instances this difference about equals the amid nitrogen con-

[1] In determining the nitrogen in the ammonia solutions of humus it was found advantageous to evaporate to dryness two portions of the solution. In one the combined ammonia only was determined, which amounts were subtracted from the total nitrogen found in the other without distilling with MgO.

tained in the sodium hydrate solutions. Rimbach[1] has shown that the humus nitrogen as determined in sodium hydrate and ammonia solutions, respectively, occurs in greater amounts in the former solutions, from which he concluded that sodium hydrate dissolves more nitrogen than ammonia. Similar observations have also been made by others. From work done in this laboratory it is doubtful whether sodium hydrate actually dissolves more nitrogen than ammonia, but rather that the increased amounts found represent amid nitrogen, which is lost in the methods employed in the determination of total humus nitrogen from ammonia solutions.

While the amounts of ammonia absorbed by the residues left after evaporating to dryness ammonia solutions of humus bear no definite relation to the amounts of humus nitrogen present, the absorption of ammonia by humus took place to a considerable extent, and correction should be made for this in humus determinations, as has been pointed out by Emery[2] and others.

PERCENTAGE OF NITROGEN IN HUMUS OF HAWAIIAN SOILS.

Hilgard[3] has shown that humus from arid regions contains a higher percentage of nitrogen than humus from humid sections. He found that humus from arid regions contained on the average 15.23 per cent nitrogen, while the humus from humid regions contained only 4.23 per cent. In the work on soils at this station many humus and humus nitrogen determinations have been made and some of the results obtained are submitted in the following table:

Total humus and humus nitrogen in Hawaiian soils.

Soil No.	Humus. Per cent of soil.	Humus ash. Per cent of soil.	Humus nitrogen. Per cent of humus.	Soil No.	Humus. Per cent of soil.	Humus ash. Per cent of soil.	Humus nitrogen. Per cent of humus.
347	14.81	2.28	5.16	285	2.03	0.63	9.85
428	14.31	3.89	4.12	286	3.15	.94	10.35
379	8.20	1.91	5.35	287	3.64	1.38	7.31
406	3.08	1.64	7.33	288	3.06	1.48	5.88
447	3.61	1.54	5.94	312	5.26	1.19	5.27
345	1.74	1.13	6.88	313	4.14	1.44	6.85
343	2.45	1.73	5.21	314	3.94	1.17	6.81
405	1.74	1.07	4.91	315	4.33	.79	6.36
292	1.80	1.87	3.21	316	3.39	.81	6.22
282	2.77	1.04	7.87	317	5.12	1.18	6.32
283	1.78	.79	6.40				
284	2.72	.70	5.62	Average			5.88

These data show that the humus of Hawaiian soils contains nitrogen in amounts similar to those of humid soils elsewhere. Some of the soils used in this investigation (Nos. 379 and 447) came from sections which have been designated as arid, but the arid conditions which now prevail in these sections have probably not existed as such for

[1] Loc. cit.

[2] Jour. Amer. Chem. Soc., 22 (1900), p. 285.

[3] Soils. New York and London, 1907, pp. 136, 137.

many generations, perhaps not more than 75 years, and the humus has been formed largely under humid or semihumid conditions.

It is probable that oxidation takes place more actively in arid than in humid soils, which oxidation probably results in a greater degree of decomposition of the nonnitrogen constituents, thus leaving a humus residue richer in nitrogen. Also, the humus may be considered as being older than that occurring in humid soils, for the reason that greater amounts of plant residues are continually becoming incorporated with the soils under conditions that are more favorable for plant growth, such as are offered by a more abundant moisture supply. For these reasons (perhaps others) it is to be expected that the humus of arid soils would be more largely composed of nitrogen constituents than that of humid soils.

SUMMARY.

(1) The nitrate and ammonia content of Hawaiian soils constitutes only a small percentage of the total soil nitrogen.

(2) Upon boiling different soils with strong hydrochloric acid, the amounts of nitrogen dissolved ranged from 67.51 per cent to 91.88 per cent of the total nitrogen. With two exceptions, the relative percentages of amid nitrogen, split off in the hydrolysis, were approximately the same, amounting on the average to 23.91 per cent of the nitrogen dissolved. Basic nitrogen occurred in the solutions in variable amounts, the average being 9.98 per cent of the soluble nitrogen. The percentages of nonbasic nitrogen, determined by difference, proved to be quite concordant in most of the soils, amounting on the average to 64.57 per cent of the soluble nitrogen.

(3) The relative percentages of amid and basic nitrogen, split off in the hydrolysis of Hawaiian soils, stand in the reverse order to that in which they occur in the vegetable proteins; while the percentage of nonbasic nitrogen practically equals that found in the vegetable proteins. It had been suggested that soil bacteria attack the nitrogen bodies in such way as to split off the basic nitrogen compounds, and that these then become ammonified, or otherwise lose their identity as diamino acid compounds, possibly being partially converted into amid forms.

(4) Anaerobic conditions predominate in Hawaiian soils, and under such conditions the nitrogen is more soluble than in well aerated soils, but the relative percentages of the different groups of organic nitrogen compounds seemed not to be affected by the predominance of one or the other of these conditions.

(5) The amount of nitrogen soluble in 1 per cent hydrochloric acid was about twice as large as that of ammonia originally occurring in the soils.

(6) The solubility in 3 per cent sodium hydrate varied from 49.56 per cent to 76.62 per cent of the total nitrogen. Of the nitrogen thus dissolved, 57.85 per cent was precipitated by dilute hydrochloric acid, of which 11.93 per cent (expressed in percentage of the humus nitrogen) remained insoluble after boiling in strong hydrochloric acid for 10 hours. Amids comprised 28.77 per cent of the humus nitrogen, of which about one-half existed as amid in the original humus solutions, and which remained in solution upon acidifying with hydrochloric acid. The remaining half was split off when the humus, precipitated by hydrochloric acid, was subjected to acid hydrolysis. The basic nitrogen ranged from 4.39 per cent to 44.83 per cent of the humus nitrogen, increasing as the total nitrogen of the humus decreased. Nonbasic nitrogen was found to constitute 53.38 per cent of the humus nitrogen, of which 25.05 per cent existed as such in the original humus solutions.

(7) The amounts of amid and basic nitrogen in humus expressed as percentages of the humus nitrogen were found to be higher than the amounts obtained by subjecting the original soil to hydrolysis.

(8) In view of the large amounts of amid occurring in humus solutions, it was found better to use sodium hydrate as the solvent for extracting humus that is to be used for total humus nitrogen determinations.

(9) The humus of Hawaiian soils contains a small percentage of nitrogen (5.88 per cent as an average of 22 samples), in which respect the humus of these soils closely resembles that found in humid soils in the States.

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Issued May 25, 1914.

HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 34.

TOBACCO INSECTS IN HAWAII.

BY

D. T. FULLAWAY,
ENTOMOLOGIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 16, 1913.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 34 of the Hawaii Experiment Station a paper on Tobacco Insects in Hawaii, by D. T. Fullaway, entomologist. The extension of the tobacco industry in Hawaii in the past few years has made desirable a further study of the insect pests of tobacco, and the results of these studies, together with practical recommendations for the control of tobacco insects, are presented in this bulletin.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

CONTENTS.

ILLUSTRATIONS.

TOBACCO INSECTS IN HAWAII.[1]

INTRODUCTION.

A general account of the insects known to feed on tobacco was presented as a bulletin of this station by D. L. Van Dine.[2] This bulletin, however, was prepared while the experimental work on tobacco was still in progress and before any large areas had been planted. In the meantime the industry has become established and the plantings greatly extended, and in view of the facilities for obtaining and importance of having actual and complete information in regard to the pests encountered in the tobacco fields, the entomological work reported herein was begun several years ago and continued to date. The present paper, then, is intended to supplement the information contained in the previous bulletin, and in addition to listing the insects gives an account of the distribution, life history, habits, means of control, and natural enemies of each of the species enumerated, together with other data gathered through study and observation during the course of the work.

The principal tobacco pests are cutworms, splitworm, pod-borer, hornworm, flea-beetle, and cigarette beetle. Many minor pests are also encountered without being especially destructive. These may be discussed in two categories, namely, those affecting the plant and those affecting the product.

INSECTS AFFECTING THE PLANT.

CUTWORMS.

Cutworm is a general term used to designate the large ground-inhabiting caterpillars of the noctuid moths which usually leave their diurnal retreats at night to feed on any vegetation at hand. "Peelua" is the native word by which these worms are known. The Noctuidæ are represented in these islands by 35 or more native and introduced species. Of these, however, only eight are commonly found in cultivated fields; the others are more or less confined to the mountains and the native flora and are not generally encountered as agricultural

[1] The habits and life histories of the cutworms, splitworm, tobacco pod-borer, hornworm, tobacco flea-beetle, and cigarette beetle, and a number of pests of minor importance in Hawaii are described, and practical recommendations are made regarding the control of each of them.

[2] Hawaii Sta. Bul. 10.

pests. While the cutworms as a group are generally held in check by very efficient parasites, on account of their great reproductive powers and the wide range of their food plants they are seasonally very destructive, especially in newly broken or poorly cultivated fields, when a dearth of food compels them to migrate in numbers. The winter months, when the parasites are numerically at a low ebb and the reviving vegetation gives the cutworms an impetus to increase, are usually the season of cutworm activity and widespread destruction of crops.

Caradrina reclusa is the species most commonly found in the tobacco fields in Hawaii (fig. 1). This is a recently introduced species, not listed in the Fauna Hawaiiensis. According to Swezey, it was first noticed in numbers in 1906, although Perkins had taken

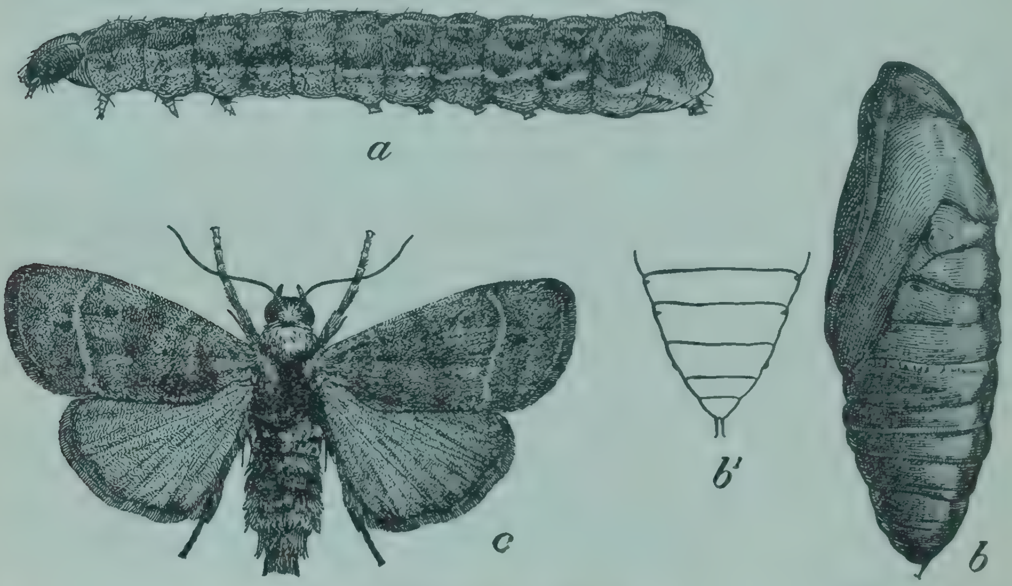

FIG. 1.—*Caradrina reclusa*, a cutworm common in tobacco fields: *a*, Larva; *b*, pupa; *c*, moth. (Original.)

specimens a few years previous to 1906. Its habitat is given as Nilgiris, Ceylon, Borneo, and Fiji, and it has probably come to Hawaii from the last-named locality.

A full account of its life history is given by Swezey,[1] from which the following data are taken:

The eggs are not laid in a mass or cluster, but are scattered around singly or in small numbers; on the surface of grass leaves they are sometimes laid in rows; they are also at times placed on any hard surface. One moth in captivity laid 216 eggs. It died after four days.

The egg is hemispherical, with the flattened surface next the leaf; it is ribbed meridianally with about 30 ribs, 10 of which reach the upper pole; there are also slight cross ridges between the ribs; at the

[1] Proc. Haw. Ent. Soc., 2 (1908), No. 1, p. 3.

upper pole is an irregular patch of reddish color; there is also an irregular ring of the same color at about one-third the distance from pole to base of egg; the rest of the egg is pale green; when first laid it is entirely pale green.

The full-grown larva is 26–32 mm. long and almost black. The two preceding stages are more mottled and variegated with black, brown, olivaceous, yellowish and whitish, darker colors, however, predominating. There are two more or less conspicuous subdorsal rows of black spots on segments 7–12 and a broad paler region on dorsum between these, in the middle of which is a series of obscure lozenge-shaped darker spots. The head is mostly black except the periphery (i. e., the portion covered when retracted), which is pale brown. There are two conspicuous whitish subdorsal spots on segment 6, and the posterior subdorsal parts of segment 12 and upper parts of segment 13 are yellowish. The spiracles are black with a yellowish streak below them. The tubercles are not conspicuous but about the same color as their surroundings, and the hairs are short. The twelfth segment is quite swollen. The duration of the larval stage is 30–40 days.

Fig. 2.—*Frontina archippivora*, parasitic on cutworms. (From Swezey.)

The pupa is formed in the soil, an inch or two below the surface. It is 13–15 mm. long, uniform medium brown; eyes black; wing, leg, and antennal cases extending to apex of fourth abdominal segment; the articulations between segments 4–7 movable. There is a row of about 20 pits on dorsal part of basal margin of segments 5, 6, and 7, from the ends of which a band of punctures extends around the ventral side. The apex of the abdomen is blunt and rounded, with two approximate dark spines, the tips of which converge and are slightly curved ventrally. The pupal period is 12–14 days.

The moth is described as follows:[1]

♀ Pale chestnut brown. Fore wing with very faint traces of the usual markings; a prominent ochreous postmedial line slightly curved from the costa to vein 2, and not waved. Hind wing paler.

♂ With the collar and abdomen black; the second joint of palpi black. Fore wing with the basal area clothed with ocherous hair; hind wing with the base yellowish; some specimens have a black speck in cell of fore wing and series of specks on the postmedial line and margin.

On the few productive plantations here this cutworm is by long odds the most destructive pest encountered. Six and seven replant-

[1] Hampson. Fauna Brit. India; Moths, 2 (1894), p. 264.

ings are often required to secure a stand, in spite of the most thorough distribution of poisoned bait and handpicking. Inability to control the cutworms in these plantations is due largely to the character of the land, which is rocky and unworkable. With thorough cultivation, cutworms become almost a negligible quantity after the lapse of several years, except for occasional outbreaks which are, for most species, of rare occurrence.

Next to thorough cultivation the best artificial control of cutworms is secured by distributing about the plants a poisoned bait—white arsenic or Paris green in moistened and sweetened bran, flour, or middlings. The edges of fields adjacent to uncultivated land are often trenched, so as to present a steep surface on the exposed side which the cutworm can not climb. Hand picking is sometimes resorted to, but is altogether too slow and expensive.

As already stated, the present parasites of cutworms are fairly efficient throughout the year; these are the tachinid flies, *Frontina archippivora* (fig. 2) and *Chætogædia monticola*, the ichneumon fly, *Ichneumon koebelei* (fig. 3), and the egg parasite, *Trichogramma pretiosa*.[1] Birds also devour large numbers.

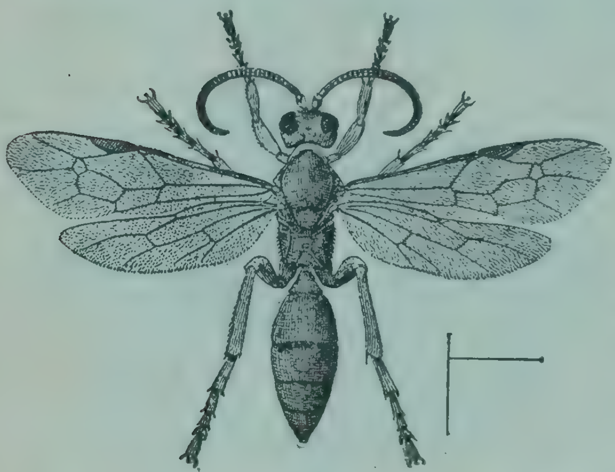

FIG. 3.—*Ichneumon koebelei*, parasitic on cutworms. (From Swezey.)

The loss from cutworm injury, especially in diversified farming, is a serious matter and should have more attention than it at present receives. For instance, with Government assistance it might be possible to get by importation many additional cutworm parasites. Insectivorous birds also should be protected by law or by the cooperation of owners of land used for agricultural purposes, and more insectivorous species might be secured by importation.

SPLITWORM.

The splitworm of tobacco is the caterpillar of the common gelechiid moth, *Phthorimæa operculella* (fig. 4), a widely distributed pest of Irish potatoes, tomatoes, eggplants, and other solanaceous plants, as well as of tobacco. The moth was described in 1878 from specimens from Texas and its destructiveness to solanaceous plants came to notice shortly afterwards. Within a decade it was reported as an agricultural pest from various parts of the United States and the

[1] This parasite, or *T. flavum*, which is probably only a synonym of *T. pretiosa*, has been bred from the eggs of a noctuid, probably *Spodoptera exigua*.

West Indies, from Algeria and the Canary Islands in Africa, and from Australia and New Zealand in Polynesia. It was first noticed in Hawaii in 1892 by Perkins and Blackburn, when it had undoubtedly been here some time.

The caterpillar, as indicated in the designation "splitworm," mines the leaves of its host plants, making a broad, flat track through the mesophyll between the upper and lower epidermis, which often becomes badly split and shattered when dry. It sometimes also tunnels the stem, which thereby becomes greatly weakened.

As a tobacco pest this species is most injurious to seed bed plants. When the seed bed is invaded the plants are generally set back and sturdy seedlings for transplanting difficult to obtain. This trouble may be partly overcome by seeding the beds very thin and protecting them from the moth with cotton netting. The damage to plants in the field is slight on well-conducted plantations, and it is usually only the two or three poor, soiled, lower leaves that are much split by the worm. Where, however, a planting is neglected the infestation becomes general and any tobacco in proximity to the neglected fields will be badly split.

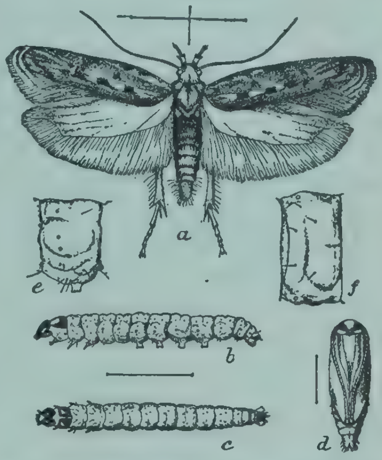

FIG. 4.—*Phthorimæa operculella*, the tobacco splitworm: *a*, Moth; *b*, larva, lateral view; *c*, larva, dorsal view; *d*, pupa; *e*, *f*, segments of larva, enlarged. (Redrawn from Riley & Howard.)

Life history.—There are four distinct stages in the life cycle of this insect, namely, the egg, larva or caterpillar, pupa, and adult.

The egg: The eggs are laid singly on the leaves, often in the hollow alongside the veins. They are oval to pear shaped, 0.45 mm. long by 0.27 mm. across, pearly white, and faintly reticulate. About 20 to 25 eggs are laid by a single moth. The egg stage occupies six days.

The larva: The full-grown larva is a rather slender worm, about 10 mm. long, in color sordid white with a greenish or reddish tinge; the head, cervical shield, legs, and antennæ brown to black. The cervical shield is broad and wide, almost reaching the posterior margin of the segment; the lateral hind angles rounded. The tubercles are fuscous to black, mostly minute, bearing setæ, and are arranged in longitudinal rows as follows: (1) anterior, (2) posterior and a trifle more removed than 1, (3) above spiracle, (4 + 5) below, (6) posterior, below fold, (7) ventral; on segments 2 and 3 (1) and (2) are in a line at about middle of segment, while (3), (4), and (5) form an equilateral triangle, (3) and (4) rather large; on first segment the spiracle is posterior, and in front of it there is a large, flat tubercle with three long hairs.

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The larval stage occupies about 26 days. Before pupating the worm usually leaves its mine or tunnel and finding a hidden or obscure corner builds a cocoon of silk and grass or grains of soil within which it pupates.

The pupa: The pupa, removed from its case, is brown, about 6 mm. long, and rather slender. The wing cases distally are free from the abdomen; the leg and antennal cases are scarcely longer than these, and reach the apex of the sixth segment. The cremaster is lobed, and between the lobes dorsally is a short, stout spine surrounded by numerous hairs with recurved tips. The pupal stage covers 11 days.

The moth: The moth is described by Walsingham [1] as follows:

Antennæ brownish cinereous. Palpi cinereous, with two umber-brown patches on the median joint externally, a spot of the same on the base of the terminal joint and a broad band before its apex. Head brownish cinereous; face pale cinereous. Thorax brownish cinereous, with three smoky brown longitudinal lines above. Fore wings dull buff-brown, shaded and spotted with dark smoky brown; this forms a dorsal shade below the fold, a terminal shade reverting around the apex, and a spot at the end of the cell from which narrow lines radiate outward along the veins; there are also two spots near the base of the costa, the first succeeded by another below and beyond it, the second followed by one on the cell and one on the fold in an oblique line, a pair of smaller spots lying beyond this line on the cell, also in oblique succession; cilia pale buff-brownish, sprinkled along their base with smoky brown. Exp. al. 15–16 mm. Hind wings pale gray; cilia pale brownish ochreous. Abdomen and legs brownish cinereous.

Remedies.—As the insect in its injurious stage is generally protected in its tunnel, poisons are of little use in attempting to control it artificially. It is well known, however, that the worm often deserts an old mine to form a new one and the hatching caterpillars must in the first place eat through the epidermis; to this extent, therefore, they are vulnerable to lead arsenate dusted or sprayed on the plants, and this measure is recommended for the control of the worm in seed beds. If the arsenic is applied as a spray it can be combined with the Bordeaux mixture used in case of fungus troubles. Under field conditions, however, the little good accomplished and the great expense involved make it scarcely worth while. As already mentioned, the beds can be protected by screening. As a precaution against a general infestation, no solanaceous plants should be grown near the tobacco fields and all solanaceous weeds in the immediate vicinity should be periodically destroyed.

Natural enemies.—The caterpillars of the splitworm are very much parasitized by a small black and white braconid, *Chelonus blackburni*, which likewise attacks a number of other small leaf-rolling caterpillars. The parasitized caterpillars spin their cocoons when about half grown without pupating. Shortly afterwards the larva of the

[1] Fauna Hawaiiensis, vol. 1, pt. 5, p. 484, 1907.

parasite emerges from the caterpillar and feeding on it externally finishes it off and spins its own delicate white cocoon inside that of its host. The parasite emerges a little later than the moth would have done.[1]

It is also much parasitized by a native ophionid, *Limnerium blackburni*, common to many of the smaller pyralids, and with very similar habits to the parasite referred to above.

FIG. 5.—*Limnerium blackburni*, parasitic on splitworm. (From Swezey.)

POD-BORER.

The tobacco pod-borer, more familiar in some quarters as the cotton bollworm and the corn earworm, is the larva, or caterpillar, of the noctuid moth *Heliothis obsoleta*, a cosmopolitan pest of omnivorous habit, often very destructive to such important field crops as cotton, corn, tobacco, tomatoes, etc. (fig. 6). On the tobacco plant its characteristic injury is the boring and eating of the seed pods, although it also eats the foliage to some extent. Curiously enough, in Hawaii it is never found on either corn or cotton and is not generally considered a serious pest to tobacco. Its multiplication is probably in some way checked or controlled, most likely by natural enemies, although these have never been disclosed.

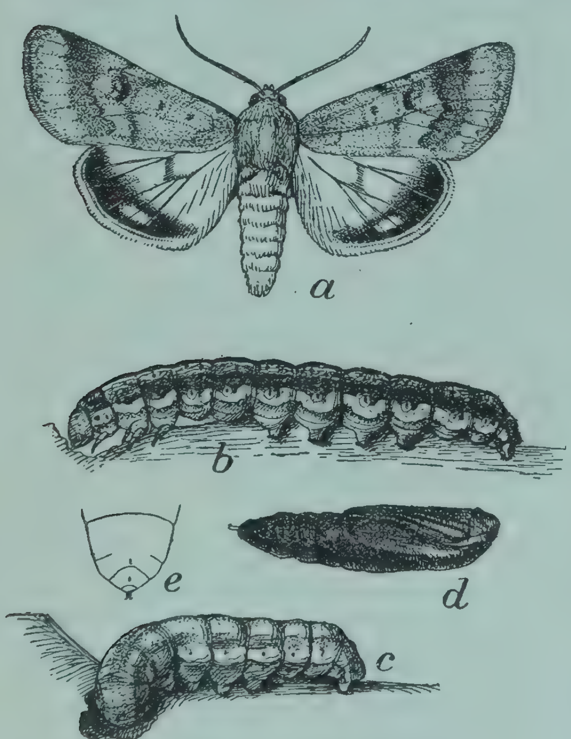

FIG. 6.—*Heliothis obsoleta*, the tobacco pod-borer. *a*, Adult moth; *b*, dark full-grown larva; *c*, light colored full-grown larva; *d*, pupa—natural size. (From Howard.)

Life history.—There are the usual four stages in its development.

The egg: The eggs are laid singly, in a considerable number, and are generally well scattered. They are rather large and conspicuous; sometimes they are found near the bud in young plants, most usually however on the flower, the pod, or the subtending bracts, rather loosely attached

[1] Hawaiian Sugar Planters' Sta., Div. Ent. Bul. 5, p. 41 (1907).

but adhering readily to the sticky surface of the plant. The egg is pearly white, spherical (diameter about 0.6 mm.), radiately ridged on the sides from a smooth circular area on the dorsal summit surrounding the micropyle, the longitudinal ridges connected by short cross ridges. The egg stage is five days.

The larva: The larva is extremely variable and for that reason difficult to describe. Freshly hatched specimens are about 0.75 mm. long, sordid white with black head and fuscous cervical shield, and covered with black hairs. Four or five molts occur in the course of its growth, the color often changing in the molt. The full grown caterpillar is 30–40 mm. long, stout bodied, the integument more or less shagreened through the presence of extremely closely set, short, stout spines; the principal varieties greenish, reddish, and grayish, and longitudinally striped—usually a broad dorsal and two broad lateral dark stripes above the pale stigmatal line, with many fine wavy lines intermixed. The head and cervical shield are brown, the latter with irregular black markings. Spiracles black with white center. Tubercles variable, some large and black, others small and pale, and arranged in longitudinal rows as follows: On segments 4–9 (1) is anterior, (2) posterior and farther removed from median line, (3) above spiracle, (4) behind and (5) under and beneath the stigmatal line; in some cases (4) is small and (5) is in all cases. On the segments with prolegs (6) is above the leg; on the segments without them (6) and (7) are ventral and posterior. On segments 2 and 3 (1) and (2) are in line and (1) is small; (3) is close to (2) and also in line; (4) and (5) are small, the latter behind the former on the stigmatal line, (6) above the leg. On segment 1 (1) is anterior, (2) posterior and farther removed, (3) is above spiracle, (4 + 5) in front, (6) above the leg. On segment 10 (4) is behind (5), which is below the spiracle; on segment 11 (4) is absent. The length of the larval stage is 32 days. When full grown the larva leaves the plant to enter the soil, fashioning a rough cell several inches below the surface in which it pupates.

The pupa: The pupa is of the usual stout noctuid type; length about 20 mm.; smooth and brown. The wing cases end broadly, the leg and antennal cases narrowly, at the apex of segment 4. The spiracles on segments 2–7 are contracted oval, raised above the integument into a short neck, and are black; that on segment 8 is a mere narrow slit. The anterior margin of segments 4–7 dorsally and 5–7 ventrally are punctate, the punctation rather fine on segment 4, otherwise coarse. The cremaster is rather pointed, with two fairly long projecting spines. The length of the pupal stage is 12–16 days.

The moth: The adult moth is described as follows:[1]

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[1] **Hampson. Fauna Brit. India; Moths, 2 (1894), p. 174.**

Ochreous with a pale brown, olive, or red-brown tinge. Fore wing with indistinct double waved antemedial lines; a dark speck representing the orbicular; an indistinct curved medial line; the reniform indistinct; postmedial and submarginal waved lines, the space between them somewhat darker and with a series of pale or dark specks on the nervules; a marginal series of dark specks. Hind wing white; the veins fuscous; a broad blackish outer border usually with a pale submarginal central patch. Underside of fore wing with the orbicular and reniform stigmata conspicuously black; a broad blackish band beyond the postmedial line; the apices of both wings and outer area of fore wing pinkish.

Remedies.—As already stated, the pod-borer is not a serious pest of tobacco. It is the general practice of planters to top the plants as soon as the flowers appear, and where this is done consistently there is little evidence of the pod-borer. To obtain seed, the flower stalks are usually inclosed in a bag. Neglected fields, however, always show signs of the borer if the eggs or worms are not actually present in numbers. Under the circumstances it is unnecessary to recommend any remedial measures beyond the avoidance of neglecting a regular routine in field work. If for any reason a field of standing tobacco is abandoned, the plants should be plowed up and destroyed to avoid a general infestation.

Natural enemies.—The eggs of the pod-borer moth are probably parasitized, here as elsewhere, by *Trichogramma pretiosa*, although the parasite has never to my knowledge actually been bred here from Heliothis eggs. It is also possible that the common tachinid parasites attack Heliothis, but there is no positive evidence at hand.[1]

HORNWORM.

Hornworms are the familiar, large, repulsive-looking caterpillars of the hawk moths, with large head and prominent horn or spine at the hind end of the body. The moths are also large and heavy-bodied and resemble humming birds as they hover around open blossoms in the late afternoon. There are several native species which are only rarely seen in the mountains, but the strong flying moths often get down to the coast. The commoner introduced species are found, *Sphinx convolvuli* on sweet potatoes and *Deilephila lineata* on purslane. The tobacco hornworm, *Phlegethontius quinquemaculata* (fig. 7), is extremely uncommon and has never been seen by the writer on tobacco. It is sometimes found around Honolulu on the wild tobacco (*Nicotiana glauca*), and on these occasions the broods are usually large, and the plants soon stripped. Its rare occurrence would indicate the presence of very efficient parasites.

The tobacco hornworm is a North American insect and is known throughout the tobacco districts of the United States as the northern tobacco worm in contradistinction to the southern tobacco worm, *P. sexta.* It must have been introduced here at an early date; it

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[1] Since the above was written, *Frontina archippivora* has been bred from the pupa.

was first recorded, however, by Blackburn in 1881 and described by Butler on Blackburn's specimens as a new species, *P. blackburni*. *P. blackburni* later proved to be a synonym, as already indicated.

The larva: The larva is described by Blackburn as follows:[1]

Green or ashy gray, more or less sprinkled with white; spiracular line white, emitting upwards and backwards (i. e., so that they slant upwards in a backward direction) seven white stripes, the first of which is on the fourth segment (not counting the head as a segment), the last on the tenth; on the eleventh segment is a small white stripe bent backwards over the spiracle, being much smaller than the white lines on the other segments; head with two well-defined black longitudinal lines, and clouded with black laterally; spiracles black, surrounded with a bright blue ring;

FIG. 7.—*Phlegethontius quinquemaculata*, the tobacco hornworm. *a*, Adult moth; *b*, full-grown worm or larva; *c*, pupa—natural size. (From Howard.)

horn long, shining black, bent backwards; claspers of the ground color. In the ashy gray larvæ the whole dorsal surface is sprinkled with white; the segment behind the head is shining black, bordered with white; the last claspers and space around the anus are shining black (at least partially); and the legs are blackish at base, becoming red toward apex. In the green larvæ only a few segments near the head are sprinkled with white, and the segment next behind the head, the last claspers, and the space round the anus are olivaceous rather than black; the legs, too, are more conspicuously red.

The pupa: The pupa is of the usual large heavy-bodied sphingid type with projecting tongue case forming the so-called "jug handle."

[1] Ann. and Mag. Nat. Hist., 5. ser., 7 (1881), p. 319.

It is described as rather slender and more or less smooth, the puncturing at base of abdominal segments and at apex fine and shallow. The wing cases are angulate, the tongue case rather long and thin, the tip touching the body at one-third the length from the head. The larvæ pupate 3 or 4 inches deep in the soil within a roughly constructed cell.

The moth: The moth is described as follows:[1]

General color ash gray; fore wings ash gray at base, without white spots. No white dot at middle of wing, this mark represented by a gray dot encircled with black, which does not contrast with the color of adjacent parts. Fringe of outer margin without white. An evident whitish line begins in an enlargement at the angle, and extends forward, parallel with the edge, toward the apex of the wing, but terminates abruptly before reaching it. Outer angle of fore wing decided. Basal two-thirds of hind wing largely light ash gray, the middle of the wing crossed by two sharply dentate black lines, which represent the more or less fused pair on the wing of *P. carolina*. Outer third of hind wing largely ash gray, this area limited within by a wide curved band of black. Head and thorax above ash gray. Abdomen on middle above ash gray, with an evident narrow median black line. Orange spots on side five in number, less elongated transversely and more rounded than in the related species. Legs gray, cross-banded with whitish above.

The following description of the Hawaiian form is copied from Butler:[2]

P. quinquemaculato simillima; major, alis latioribus, magis grisescentibus; signis alarum anticarum subcostalibus albescentibus; serie macularum albarum antice confluentium arcuata discali, cum fascia ordinaria nigrocincta cohærente; fasciola posticarum prima obsoleta; fascia sub-marginali nigra apud apicem multo latiore; alar. exp. unc. 5.

There are no breeding records at hand.

In the United States the life cycle runs through about 45 days; in Hawaii the time would presumably be somewhat shorter.

Remedies.—As already stated, tobacco growers have not found the hornworm a serious pest on account of its rarity. When it does appear it may flourish for a time and do considerable damage; in such a case it is best to check it at once by spraying infested plants with lead arsenate (3 pounds to 100 gallons of water), to which the young worms are very susceptible. If the worms have reached large size before the infestation has been noticed, hand-picking should be resorted to, as it is difficult to kill the large worms with a stomach poison.

Natural enemies.—The natural enemies are not known, but it is probably an egg parasite and not unlikely a trichogrammid. The eggs of the congener *S. convolvuli* are parasitized by the trichogrammid *Pentarthron semifuscatum*.

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[1] Garman. Kentucky Sta. Bul. 66, p. 25.

[2] Ent. Mo. Mag., 17 (1880), p. 6.

FLEA-BEETLE.

The tobacco flea-beetle, *Epitrix parvula* (fig. 8), is one of the phytophagid beetles, a family including many extremely injurious forms, such as the 10-lined potato beetle, the asparagus beetle, cucumber beetle, and a host of other flea-beetles with very similar habits but widely different food plants.

According to Sharp,[1] who vouchsafes for its specific identity, it is a late introduction, not being taken by Blackburn in his collecting here in the late seventies and early eighties. It is of American origin and is generally distributed in the Southern States of the Union, in Mexico, Central America, and the West Indies. Like some other tobacco pests, it feeds on practically all the commoner solanaceous plants, and is equally injurious to potatoes, tomatoes, eggplant, and poha. Both the larva and the adult beetle do damage, but the characteristic injury is the work of the adults on the leaves. The beetles are small and their mouth parts can grasp only small fragments, but they are assiduous feeders, so that the result of their feeding is often a shattered foliage, ragged with spots and holes and broken margins. The larvæ work beneath the surface on the roots and crown, an injury apparently of little consequence, but noticeable in neglected plants. No enemies have been disclosed, but, apparently, some factor interferes to prevent its undue multiplication, else this pest would do widespread injury. In some places there appears to be a seasonal occurrence, the beetle becoming numerous and injurious only in the dry season; but in neglected plantations, and especially in the neighborhood of other solanaceous plants, it is commonly prevalent. The adult beetle is rather long lived, but it should not on this account necessarily be more injurious, as it is able to do without food for long periods.

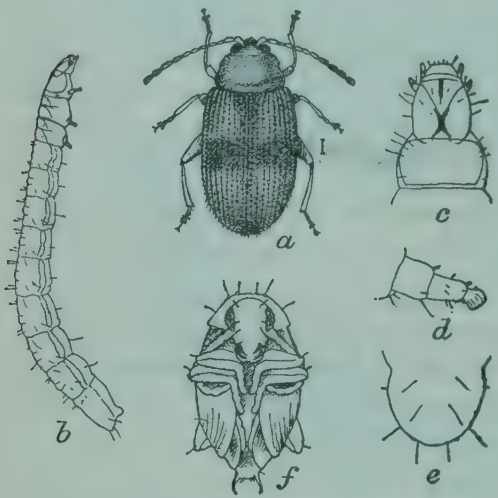

FIG. 8.—*Epitrix parvula*, the tobacco flea-beetle. *a*, Adult beetle enlarged about fifteen times; *b*, young larva; *f*, pupa; *c*, *d*, *e*, portions of the larva greatly enlarged. (From Chittenden.)

The difficult life history has been fully studied in America by Chittenden, and the writer has not attempted to duplicate this work.

Egg: The egg, according to Chittenden,[2] is narrow, elliptical-ovate, two and one-half times as long as wide, color gray with scarcely a

[1] Fauna Hawaiiensis, vol. 2, pt. 3, p. 95, 1900.

[2] U. S. Dept. Agr., Div. Ent. Bul. 19, n. ser., p. 86 (1899).

tinge of yellow, the surface divided into very minute irregular areas only visible under a high magnification. Length 0.4 mm., width 0.18 mm.

Larva: The larva, according to the same authority,[1] is 3.5 mm. long, delicate and filiform or threadlike, milky white in color except the head, which is honey yellow, and with darker brown mouth parts and sutures. The body is subcylindrical, moderately wrinkled and segmented, and sparsely covered with short hairs. The head is only moderately chitinized, and the first, thoracic, and last, or anal, segment are apparently not at all or only slightly chitinized. The anal segment is furnished with a small proleg, but there are no visible denticles at its apex.

Pupa: The pupa is white like the larva and resembles the pupa of Diabrotica, especially in the anal hooklike appendages. The insect pupates in a cell.

Adult: The adult is very minute, measuring scarcely 1.5 mm. in length, is oblong ovate in form, and light brown in color. The elytra are usually marked with a dark transverse median band of greater or less extent.

A life cycle is said to run through 28 days, as follows: Egg, 6 days; larva, 16 days; pupa, 6 days. In Hawaii it would presumably be somewhat shorter.

Remedies.—On the commercial plantations of Hawaii the flea-beetle does not seem to be much of a pest except late in the growing season, but in neglected tobacco it becomes very numerous. For this reason it is necessary in growing tobacco commercially to keep well up in the field work and allow no plants to remain around after the tobacco has been picked. Other solanaceous crops should not be grown near the tobacco, and all solanaceous weeds in the neighborhood should be periodically destroyed. When, however, the flea-beetle is present in sufficient numbers to damage the crop, the affected plants may be sprayed with arsenate of lead, 1 pound to 20 gallons of water, paste form (only one-half of this amount of powdered arsenate of lead), which will kill any beetles feeding on the sprayed foliage.

MINOR PESTS.

There are a few minor pests of tobacco, such, for instance, as the caterpillars of *Plusia chalcites* and of *Amorbia emigratella*, which are rather general feeders and are found on various cultivated and wild plants without being particularly injurious to all of them; and the mealy bugs *Pseudococcus citri* and *Pseudococcus virgatus*, which are also found on many different plants but are noticeably injurious only under exceptional circumstances. In the Kona tobacco fields

[1] U. S. Dept. Agr., Div. Ent. Bul. 10, n. ser., p. 79 (1898).

Siphanta acuta and *Pulvinaria psidii* are also found on tobacco, although they are commoner on the coffee plant, and snails do some damage to seedling and young plants. The grasshoppers, *Elimæa appendiculata* and *Xiphidium varipenne*, are frequently seen on tobacco and may feed on it to some extent, but the injury they do is altogether negligible. A rather common introduced bug (*Nysius delectus*) is also found on the seed pods of tobacco wherever grown, but it has not been ascertained whether or not it breeds on tobacco or is in any way injurious to the plant. There is also associated with tobacco a bark beetle (*Xyleborus* sp.) the larva of which mines the old stems, but it is not especially injurious.

INSECTS AFFECTING THE STORED PRODUCT.

CIGARETTE BEETLE.

The cigarette beetle, *Lasioderma serricorne* (Ptinidæ) (fig. 9), is one of those numerous species which feed altogether on dry, dead vegetable

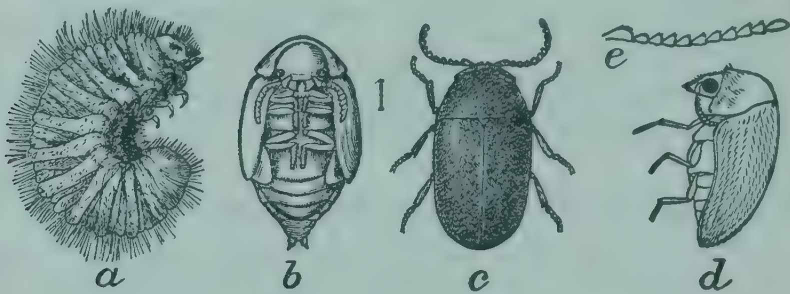

FIG. 9.—*Lasioderma serricorne*, the cigarette beetle. *a*, Larva; *b*, pupa; *c* and *d*, adult; *e*, antenna—greatly enlarged—natural size shown by hair line. (From Chittenden.)

or animal substance, and thus become pests where animal and vegetable products must be stored or kept for future use. Commercial operations and the transference of stored products from one region to another have gradually brought about a world-wide dissemination of many of these species, which in the Tropics are especially injurious and difficult to control. The attachment of the cigarette beetle to tobacco, a commodity in universal use, has given this species peculiar opportunity to attain a wide distribution, and it is now known as a practically cosmopolitan pest. It breeds, however, in various stored products in addition to tobacco—animal as well as vegetable—and often becomes a household pest, attacking the coverings of walls and furniture.

It was first recorded from Hawaii by Blackburn in 1885 [1] and is undoubtedly of early introduction. Previous to commercial tobacco growing it occasionally came to notice as a pest in houses and stores, especially in tobacconists' shops in cigar cases, and was easily con-

[1] Sci. Trans. Roy. Dublin Soc., 2. ser., 3 (1885), p. 243.

trolled by fumigation, the damage done usually being slight. However, with the commercial production of tobacco and the necessity of storing large quantities of tobacco in warehouses over long periods, the cigarette beetle has become a serious pest in the tobacco districts and its control is not at all easy—indeed, it is often practically impossible—and serious damage to the stored leaf, before it can be sold or manufactured, is unavoidable.

There is very little information of a historical, descriptive, or biographic nature in regard to the cigarette beetle. On account of its peculiar habits and common occurrence, however, the beetle is unusually well known even to the business man. It can be recognized from the following brief description: The eggs are said to be white and very minute. The larva is a short, stout, hairy, sordid white grub, between 3 and 4 mm. long, with well-defined chitinized head and three pairs of short legs. The integument of the body is much wrinkled and the body itself is usually somewhat bent. The adult beetle is about 2.5 mm. long, reddish brown, and covered with pale hairs. The antennæ are regularly serrate and fairly long. The male is slightly smaller than the female.

Mackie [1] in the Philippines states that eggs hatch 11 days after deposition and that the pupal stage covers 15 days. The length of the larval stage is not given.

Remedies.—The usual method of destroying the cigarette beetle is to expose it to the action of poisonous gases, either the fumes of carbon bisulphid or of hydrocyanic-acid gas. This method gives admirable success where the infestation is only incidental and local and the infested material can be placed in a tight compartment so that the gases can be confined and their full strength utilized. But when the infestation becomes general, as in warehouses in which stored products are being continually handled, it is exceedingly difficult to control the beetle with gases or by any other means, and the only relief that can be obtained is in a systematic fumigation of the whole warehouse from time to time, or different parts of it which can be rendered tight against the diffusion of the gas. Sometimes, also, it is a distinct advantage to spray the floors and walls with benzine or kerosene. In the tobacco industry, baled tobacco offers the greatest resistance to palliative measures, and no satisfactory method of treatment has yet been devised for it. Manufactured goods are often kept in cold storage to prevent beetle injury, and as the insect is unable to develop in the presence of such low temperatures (32 to 34° F.), the goods are safe while in storage and if not removed too soon the danger of injury after withdrawal is greatly reduced. It has, however, been shown that even low temperatures continued for

[1] Philippine Agr. Rev., 4 (1911), No. 11, p. 607.

long periods are not sufficient to destroy the vitality of the eggs of the cigarette beetle and the freezing method is therefore not absolutely preventive.

In fumigating with carbon bisulphid use it at the rate of 1 pound to 600 to 800 cubic feet of air space, pouring the liquid out into shallow pans near the ceiling (the gas is heavier than air), first making the building or compartment as tight as possible against leakage of the gas. Small lots of infested tobacco can be fumigated in air-tight boxes, using 1 ounce of carbon bisulphid to 50 to 60 cubic feet of air space. Caution is advised in the use of this chemical on account of its poisonous and inflammable nature.

Hydrocyanic-acid gas is perhaps not so effective against stored-product insects as carbon bisulphid, but has advantages in cost and ease of use. It is generated by placing cyanid of potassium in sulphuric acid and water. It is lighter than air, and therefore, contrary to the rule with carbon bisulphid, should be generated beneath. Use in proportions of 1 ounce of 98 per cent pure cyanid, 1 fluid ounce of commercial sulphuric acid, and 2 fluid ounces of water to 100 cubic feet. Care must be exercised in using this treatment on account of the very poisonous nature of the cyanid gas.

Natural enemies.—A Pteromalus was bred from this species.

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HAWAII AGRICULTURAL EXPERIMENT STATION,
E. V. WILCOX, Special Agent in Charge.

Bulletin No. 35.

ABSORPTION OF FERTILIZER SALTS BY HAWAIIAN SOILS.

Duplicate.

BY

WM. McGEORGE,
ASSISTANT CHEMIST.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
U. S. DEPARTMENT OF AGRICULTURE.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

Honolulu, Hawaii, *September 29, 1913.*

Sir: I have the honor to submit herewith and recommend for publication as Bulletin No. 35 of the Hawaii Agricultural Experiment Station, a paper on the Absorption of Fertilizer Salts by Hawaiian Soils, by William McGeorge, assistant chemist. In order to be in position to recommend a rational program for the management of Hawaiian soils it has been found necessary to make a study of all the properties of these soils. In the present paper many interesting points are brought out upon the subject of the fixing power of these soils for different fertilizer salts. It appears that the concentration of a soil solution depends perhaps more upon the fixing power of the soils than upon the solubility of the salt.

Respectfully,

E. V. Wilcox,
Special Agent in Charge.

Dr. A. C. True,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. True, *Director.*

Publication authorized.
D. F. Houston, *Secretary of Agriculture.*

CONTENTS.

ABSORPTION OF FERTILIZER SALTS BY HAWAIIAN SOILS.

In undertaking investigations on soil fertility it is very necessary to have some knowledge of the absorptive or fixing power of a soil, since this factor is one of prime importance in the successful use of fertilizers and varies greatly with the physical structure, the organic matter content, and other factors of a chemical and biological nature.

OBJECT OF WORK.

The object of the work here presented was to give some understanding of the absorptive power of Hawaiian soils for fertilizer salts. These soils contain an abnormally high percentage of iron and aluminum compounds, and from their physical condition would be expected to have a high fixing power. Many of the soil types of the islands also contain large amounts of organic matter and humus. J. T. Crawley [1] carried on some experiments with Hawaiian soils to determine the effect of irrigation upon added fertilizer salts. He found phosphoric acid to be firmly fixed, while ammonium sulphate and potassium sulphate were not so strongly fixed.

SOIL TYPES USED.

Soils representing in a general way the important types of the islands were selected for the work. The following table shows the chemical composition of the soils, as determined by digestion in hydrochloric acid of specific gravity 1.115:

Composition of soils used in the experiments.

Constituents.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Soil No. 517.	Soil No. 518.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Moisture	7.65	15.00	14.95	13.59	3.54	3.97
Volatile matter	8.42	25.58	22.24	20.01	13.71	13.56
Insoluble matter	38.49	15.10	34.99	33.77	41.99	41.53
Ferric oxid (Fe_2O_3)	16.63	19.20	8.24	7.00	21.76	21.46
Alumina (Al_2O_3)	12.85	16.64	10.73	16.79	17.23	18.21
Titanium oxid (TiO_2)	2.00	4.20	3.20	1.80	....	....
Manganese oxid (Mn_3O_4)	.24	.06	.20	.07	.12	.04
Lime (CaO)	1.84	.50	1.91	3.80	.36	.20
Magnesia (MgO)	8.71	1.80	2.24	.85	.32	.24
Potash (K_2O)	.39	.15	.24	.72	.54	.66
Soda (Na_2O)	1.36	.68	1.40	.10	.23	.46
Sulphur trioxid (SO_3)	.08	.53	.45	.45	.58	.52
Phosphoric acid (P_2O_5)	.57	.29	.22	2.18	.13	.16

[1] Jour. Amer. Chem. Soc., 24 (1902), p. 1114; 25 (1903), p. 47.

Soil No. 292. This type of soil occurs in the lowlands in and about Honolulu, now being used for growing bananas, rice, and for truck farming. It has a sandy texture, being partly derived from black or volcanic ash. It has a grayish-brown color, abnormally high magnesia content, and low content of organic matter.

No. 448 represents the type of yellow clay scattered throughout the islands, this sample being taken near Hilo, Hawaii.

No. 428 is a dark colored, highly organic soil from Glenwood, Hawaii. It has a very sandy texture, is subject to heavy rainfall, and is rather unproductive.

No. 474 is a sample of soil from Parker ranch, Waimea, Hawaii. It is a brown-colored soil of floury texture and very productive.

No. 517 represents the type of soil which is most abundant in the islands, namely, the heavy red clay, a highly ferruginous type.

METHOD.

The method of treatment adopted in this investigation was as follows: 100 grams of air-dry soil was placed in glass tubes, 1 inch in diameter, and fitted with rubber stoppers and pinchcock to regulate the passage of the solution through the soil. The percolation was regulated to flow at a rate of 100 cubic centimeters in 24 hours, and each successive 100 cubic centimeters of percolate was analyzed. The salts used were sodium nitrate, potassium phosphate, and calcium phosphate, separately and as a mixture. One series was also heated to 230° C. and another treated with chloroform to determine the effect of these agents upon absorption. All determinations were made by colorimetric methods, except those of potash, which was precipitated and weighed as potassium chloroplatinate.

ABSORPTION OF PHOSPHORIC ACID.

In this series the percolation was carried on for nearly two months, 5 liters of the solution of potassium phosphate passing through the soil. The solution used contained about 200 parts phosphoric acid (PO_4) per million, and each time a new solution was made up the strength was determined by analysis. Owing to the fact that percolation through a column of the soil was found to be impossible, due to the strong deflocculating effect of this salt, the percolation in this series was carried on in funnels. Even then several of the samples filtered very slowly. The filtrate from the clay soil was very cloudy, and the percolates became slightly stagnant in several instances after the percolations had been carried on for about one and a half months.

In order to get a clear conception of the fixation of phosphates it is necessary to have some idea of the solubility of phosphoric acid already present in the soil when treated in the same way as in the

experiments. For this purpose the glass tubes were filled with 100 grams of soil, covered with distilled water, and each 100 cubic centimeters of filtrate analyzed.

Phosphoric acid removed from the soils by distilled water.

[Expressed in parts per million of PO_4 in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	6.4	3.2	3.8	3.8	500	5.6	2.8	4.6	7.0
200	....	....	4.4	4.4	600	11.2	2.0	4.4	10.8
300	8.8	....	....	....	700	12.0	2.0	6.0	5.2
400	3.8	....	3.2	5.0	800	10.8	3.6	20.0	11.2

The general tendency of these soils is to yield a solution of fairly constant concentration. This is in direct harmony with what should be expected, namely that the phosphoric acid is so firmly retained by Hawaiian soils that the first leachings should not yield a more concentrated solution than those following.

The following table shows the absorbing power of the soil for phosphoric acid in monopotassium phosphate (KH_2PO_4):

Absorption of phosphoric acid from a solution of monopotassium phosphate (KH_2PO_4).

[Expressed in parts per million of PO_4 in the percolate.]

SOLUTION CONTAINED 175 PARTS PER MILLION PO_4.

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	45.6	13.6	11.2	17.2	2,100	62.8	4.0	5.2	25.6
200	35.2	29.0	13.2	40.0	2,200	60.0	5.2	4.8	38.4
300	52.0	10.4	17.2	44.0	2,300	60.0	4.0	4.0	22.4
400	38.0	13.6	34.0	49.0	2,400	66.4	5.6	6.0	22.4
500	39.0	9.6	19.4	36.0	2,500	62.8	4.8	4.8	31.2
600	48.0	11.2	15.6	39.0	2,600	56.0	4.8	4.8	16.8
700	57.0	15.6	16.8	42.0	2,700	44.0	4.0	4.8	32.0
800	27.0	36.0	36.0	55.0	2,800	28.8	4.0	4.8	28.8
900	20.0	5.8	20.8	35.6	2,900	31.2	3.6	4.0	35.2
1,000	17.8	5.8	27.8	41.6	3,000	39.2	4.4	4.4	32.0
1,100	71.2	5.2	12.0	24.8	3,100	21.6	4.0	4.0	24.0
1,200	37.2	6.8	13.2	40.0	3,200	6.8	5.6	5.6	26.4
1,300	72.0	6.4	14.0	34.4	3,300	33.6	5.6	5.6	44.0
1,400	60.0	10.0	16.8	20.8	3,400	25.6	10.0	29.6	36.8
1,500	76.0	7.2	12.0	52.0	3,600	20.8	8.0	8.8	29.6
1,600	72.0	5.6	11.6	56.0	3,800	46.6	10.0	9.6	31.2
1,700	42.0	13.6	12.0	24.0	4,000	29.6	4.4	6.4	34.4
1,800	64.0	9.6	8.0	20.0	4,200	46.4	5.2	12.4	48.0
1,900	66.4	4.4	4.4	18.0	4,400	34.4	4.8	8.0	48.0
2,000	54.4	4.0	4.0	14.8					
SOLUTION CONTAINED 140 PARTS PER MILLION PO_4.									
4,600	40.0	6.0	7.6	24.0	5,000	34.4	4.0	4.0	24.0
4,800	24.8	6.8	8.4	23.2					

Summary of above table.

Soil No.	PO_4 added to 100 gm. soil.	PO_4 fixed by 100 gm. soil.	Per cent of PO_4 fixed.
	Gram.	*Gram.*	
292	0.8540	0.6872	80.6
448	.8540	.8146	95.5
428	.8540	.7977	93.3
474	.8540	.6882	80.7

The amount of phosphoric acid fixed from a solution of monocalcium phosphate ($CaH_4(PO_4)_2$) is shown in the following table:

Absorption of phosphoric acid from a solution of monocalcium phosphate ($CaH_4(PO_4)_2$).

[Expressed in parts per million of PO_4 in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
SOLUTION CONTAINED 232 PARTS PER MILLION PO_4.									
100	40.0	10.4	9.6	24.8	500	33.0	16.0	15.2	39.0
200	24.0	7.2	9.2	18.4	600	17.2	11.6	11.2	19.2
300	23.2	10.8	8.0	22.4	700	13.6	11.6	10.4	16.8
400	50.0	14.0	14.4	41.0					
SOLUTION CONTAINED 220 PARTS PER MILLION PO_4.									
800	11.6	11.6	11.2	14.4	1,200	14.4	6.0	6.4	11.6
900	15.6	4.4	6.4	11.2	1,300	18.4	4.0	8.4	13.6
1,000	24.0	4.0	4.8	21.2	1,400	28.8	5.2	10.0	17.2
1,100	30.4	4.8	6.0	21.6	1,500	17.6	4.4	8.0	21.6
SOLUTION CONTAINED 132 PARTS PER MILLION PO_4.									
1,600	44.0	4.4	4.0	21.6	2,000	22.4	4.0	4.0	16.8
1,700	22.4	4.0	5.6	14.4	2,100	21.6	5.2	7.2	16.8
1,800	17.6	4.0	8.0	15.2	2,200	35.2	5.6	6.4	17.6
1,900	17.6	4.8	7.6	14.4					
SOLUTION CONTAINED 200 PARTS PER MILLION PO_4.									
2,400	36.0	12.4	17.2	25.6	2,800	22.4	12.4	10.0	18.4
2,600	22.4	4.0	7.2	12.8	2,900	20.8	5.2	5.6	16.4
SOLUTION CONTAINED 240 PARTS PER MILLION PO_4.									
3,100	39.2	4.0	8.4	24.8	3,500	16.8	5.2	5.6	18.4
3,300	76.0	4.8	8.0	36.8					
SOLUTION CONTAINED 240 PARTS PER MILLION PO_4.									
3,700	28.0	10.0	12.0	14.0	3,900	24.0	4.0	6.4	13.6

Summary of above table.

Soil No.	PO_4 added to 100 gm. soil.	PO_4 fixed by 100 gm. soil.	Per cent of PO_4 fixed.
	Gram.	*Gram.*	
292	0.8308	0.7190	86.4
448	.8308	.8043	96.7
428	.8308	.7966	95.8
474	.8308	.7516	90.4

The series reported in the above table was started in glass tubes, 100 grams of soil being used in each instance, but it was found necessary to transfer the soils to funnels, as there was no percolation at all through soil No. 474, and it was extremely slow in Nos. 292, 448, and 428. The extracts all came through clear for about one month, after which they began coming through cloudy, and when the series was stopped the percolation was very slow even in the funnels.

Phosphoric acid being the constituent of phosphates which forms insoluble compounds with the bases always present in soils, such as iron, aluminum, titanium, lime, and magnesium, it is not very difficult to understand the retention of soluble phosphoric acid by soils. In the presence of sufficient calcium carbonate the application of soluble phosphoric acid will result in a "reversion" of the phosphate, i. e., the formation of the less soluble dicalcium phosphate which, however, is quite readily available, and hence there results a gain rather than a loss. But in case the soil is deficient in lime and contains an excess of iron and aluminum hydrates and silicates, similar to Hawaiian soils, an entirely different problem is encountered. In this case the phosphoric acid will be fixed by the iron and aluminum compounds, thus being rendered not only practically insoluble in water, but also in weak organic acid solvents. For such conditions various investigators recommend the application of lime preceding that of the superphosphate, the theory being that the lime will revert the phosphoric acid. This theory has been put in practice in the red clay soils of the Wahiawa district of Oahu, but has failed to produce any beneficial results. This is probably due to the excessive amounts of iron and aluminum hydrates in these soils.

As indicated in the preceding tables, there is considerable difference in the absorption of the potassium and calcium phosphates. Since they were not carried to the saturation point, we can only compare the rates of absorption, and here the fixation of calcium phosphate is strikingly faster. It will be seen that more phosphoric acid was fixed from calcium phosphate in two of the soils and practically the same in the other two, even though 1 liter more of the potassium phosphate solution was passed through. On the other hand, nearly the same weight of the salt has passed through, and the general property of absorption is similar. In both cases soil No. 292 fixed the least phosphoric acid, No. 474 next least, No. 428 next, and No. 448 the most. Both of the soils that fixed the least phosphoric acid contained a high percentage of phosphoric acid, a sufficiency of lime, and a high percentage of organic matter. It is probable that reversion takes place more quickly with the calcium salt, which accounts for the higher rate of fixation in this case. There appears to be little correlation between the rate of fixation and the mechanical composition of the soil in cases where the size of the particles is offset by the organic matter,

the highest and the lowest in fixing power being both sandy soils but differing in organic-matter content. The fact that the fixation of phosphoric acid from the calcium salt was not excessively greater than that from the potassium salt was probably due to the fixation being largely a result of the action of iron and aluminum compounds and only a partial reversion of the calcium salt. Crawley[1] found that upon irrigating Hawaiian soils immediately after application of water-soluble phosphate one-half of the phosphoric acid remained in the first inch of soil, nine-tenths in 3 inches, and practically all in 6 inches of the surface soil. These results indicate the absolute necessity of turning all applications of phosphate under by deep plowing in order to get the best results. Otherwise the rain is not able to wash it down to the roots, and consequently the dissemination of this fertilizer is incomplete.

At the point where these series were stopped the soils had apparently lost none of their fixing power. This fact lends very strong proof to the theory that the concentration of the soil solution with regard to phosphoric acid is not increased by the addition of this element in moderate quantities either as a soluble or insoluble salt; also, that while there are differences in the concentration of the solution in different soils, they are due to factors other than the solubility of the salt in water.

ABSORPTION OF POTASH.

For the study of the absorption of potash a solution of potassium sulphate, containing about 200 parts per million of potassium (K) was used. The soils were the same as used in the phosphate series, and the method of percolation was through a column of 100 grams of the soil placed in glass tubes, as already described. At the outset the solution percolated quite rapidly, but after five days much more slowly in soils Nos. 292 and 428, and extremely slowly in soil No. 448. A precipitate, apparently of ferric hydrate, formed upon standing overnight in the extract from soil No. 292. After about one month the percolation from soil No. 448 (yellow clay soil) became so slow as to be several hundred cubic centimeters behind the rest of the series. However, strange to say, about one week following the date of above conditions, the percolation in soil No. 448 was faster than with the other soils, and when the experiments were stopped soil No. 474 was percolating the most slowly of all.

In order to get a clear conception regarding the absorption of potash, it is of some value to know the effect of leaching the soils with water upon the solubility of this element. The table following throws some light upon this.

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[1] Jour. Amer. Chem. Soc., 24 (1902), p. 1114.

Potash removed from the soils by distilled water.

[Expressed in parts per million of K in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	52	44	44	108
200	....	20	44	68
300	44	28	28	52
400	40	8	16	56
500	20	20	16	44

Thus it is shown that the general tendency of the soils was to yield a solution of fairly constant concentration. However, attention should be called to the fact that these figures do not represent parts per million in the soil, but simply in the solution obtained through percolation.

The following table shows the absorbing power of the soils for potash, using a solution containing 214 parts per million of potassium sulphate.

Absorption of potash from a solution of K_2SO_4.

[Expressed in parts per million of K in the percolate.]

Percolates of of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	60	52	48	100	1,800	140	164	184	172
200	52	92	56	80	1,900	132	148	188	160
300	40	80	40	76	2,000	128	164	192	176
400	64	100	52	84	2,100	120	188	180	168
500	76	140	124	104	2,200	100	172	184	156
600	56	148	152	88	2,300	148	172	188	180
700	60	160	156	96	2,400	132	200	172	156
800	72	164	188	84	2,500	116	200	180	168
900	76	188	192	88	2,700	136	200	200	188
1,000	76	168	192	76	2,900	152	204	216	168
1,100	64	168	212	72	3,100	152	224	224	184
1,200	84	196	192	84	3,300	184	212	232	204
1,300	136	208	200	84	3,500	152	220	216	208
1,400	96	204	204	104	3,700	160	204	224	212
1,500	120	172	200	116	3,900	148	216	204	168
1,600	128	160	204	140	4,100	164	228	200	200
1,700	124	160	196	160	4,300	164	220	228	212

Summary of above table.

Soil No.	K added to 100 gm. soil.	K fixed by 100 gm. soil.	Per cent of K fixed.
	Gram.	*Gram.*	
292	0.9030	0.4030	45
448	.9030	.1496	17
428	.9030	.2380	26
474	.9030	.2782	31

In order more easily to explain the absorption of potash by soils it is of considerable importance to know the effect of the addition of potash upon the solubility of the other bases commonly occurring in soils. For this reason several determinations were made to ascertain the concentration of lime and magnesia in the filtrate. The table following gives the results of these determinations.

Effect of the potassium sulphate solution upon the solubility of lime and magnesia in the soils.

[Expressed in parts per million in the percolate.]

Percolates of 100 cc. each.	Lime.				Magnesia.			
	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	104	44	40	514	102	24	34	82
300	56	28	10	146	70	34	28	46
500	66	22	24	150	94	32	26	40
700	50	20	24	158	72	32	18	38
900	68	36	24	164	68	26	22	38
2,700	36	24	12	70	32	24	22	24
3,300	26	14	8	48	54	26	34	34

The data presented in the preceding tables throw considerable light upon the retaining power which Hawaiian soils possess for potash. In the absorption of potash the salts undergo a decomposition, the result of which is a replacement of calcium or magnesium by potassium. The two former elements combine with the acid constituent of the potash salt and pass off in the drainage water. It has been found that potassium sulphate is more firmly fixed than the chlorid. In general the reaction taking place is a replacement of the calcium in the zeolitic silicates, but humus and the iron and aluminum hydrates also fix potash to a certain extent.

It may be seen from the above tables that the soil highest in lime and magnesia had the highest fixing power for potash, and the other three soils in proportion. This is in agreement with the findings of other investigators. Crawley [1] found that Hawaiian soils fixed potash quite firmly, but the fixation was not nearly so lasting as that of phosphoric acid. The results given herewith indicate this to be true and also the saturation point for potash to be far below that of phosphoric acid, even in the soils high in lime and magnesia. In the preceding table there are some very striking results showing the decrease in concentration of lime and magnesia in the filtrate, with decrease in amount of potash fixed by the soil. The fixation of this element in the soils highest in lime and magnesia is almost constant for the first liter of solution passing through the soil column. On the other hand, the fixing power of the other soils decreases more rapidly and they are more easily saturated, while the soil containing 8 per cent of magnesia had not reached a state of saturation at the close of the experiments.

ABSORPTION OF NITROGEN.

AMMONIUM SULPHATE.

This series was carried out in a manner similar to the previous one—namely, 100 grams of soil was placed in glass tubes, with percolation at the rate of 100 cubic centimeters per 24 hours. The percolate

[1] Jour. Amer. Chem. Soc., 25 (1903), p. 47.

remained clear through the series, except for a flocculent precipitate which appeared to be ferric hydrate, and which was deposited from soil No. 428.

The following table shows the amount of ammonia nitrogen removed from the original soils by distilled water:

Ammonia nitrogen removed from the soils by distilled water.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	6.5	11.4	13.4	4.2
200	5.7	8.4	8.8	4.4
300	2.2	5.7	5.4	2.3
400	2.9	5.7	6.4	3.0
500	....	5.6	7.3	5.1

From these data it may be seen that these soils possess the same general tendency to produce a solution of constant nitrogen content.

In the following table may be observed the absorbing power of the soils for nitrogen in ammonium sulphate:

Absorption of nitrogen from a solution of $(NH_4)_2SO_4$.

[Expressed in parts per million nitrogen in the percolate.]

SOLUTION USED CONTAINED 171 PARTS PER MILLION NITROGEN.

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	3.6	46.8	39.6	2.6	1,100	21.4	42.8	39.6	17.1
200	2.6	64.4	64.4	2.6	1,200	51.5	51.5	51.5	46.8
300	3.6	36.8	34.2	8.6	1,300	51.5	46.8	51.5	51.5
400	5.6	39.6	39.6	7.4	1,400	51.5	57.2	64.4	46.8
500	12.8	36.8	39.6	2.6	1,500	51.5	57.2	62.9	51.5
600	14.7	51.5	51.5	4.5	1,600	68.4	73.6	68.4	57.2
700	22.8	51.5	44.8	5.4	1,700	64.4	68.4	75.2	64.4
800	15.8	39.6	36.8	12.1	1,800	64.4	87.1	87.1	73.6
900	17.1	36.8	36.8	12.8	1,900	86.0	94.4	86	80.8
1,000	18.7	42.8	39.6	15.8					

SOLUTION USED CONTAINED 168 PARTS PER MILLION NITROGEN.

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
2,000	70.8	73.6	78.8	73.6	3,100	119	126	134	112
2,100	76.4	91.6	73.6	73.6	3,300	117.6	135.2	156.8	124.8
2,200	123.6	128	117.9	96.6	3,500	186	163	138	148
2,300	105.2	93.3	117.1	73.2	3,700	156.5	148.9	115.6	139.8
2,400	114.1	128.8	128.8	128.8	3,900	152.4	149.9	88.8	137.6
2,500	121.2	121.2	128.8	121.2	4,100	152	152	120.8	141.6
2,700	117	156.6	174.2	143	4,300	147.2	137.6	120	120
2,900	156.4	158.4	167.8	140.7	4,500	164.8	171.2	164.8	164.8

Summary of above table.

Soil No.	Nitrogen added to 100 gm. soil.	Nitrogen fixed by 100 gm. soil.	Per cent of nitrogen fixed.
	Gram.	*Gram.*	
292	0.6811	0.2782	41
448	.6811	.2290	34
428	.6811	.2753	40
474	.6811	.3015	44

The nature of the reaction accompanying the absorption of ammonium compounds is very similar to that of potash salts, namely, the replacing of calcium in humus, double silicates, and in some cases calcium carbonate. Hence the application of ammonium salts as fertilizer tends to deplete the soil of its basic constituents.

It may be seen from a comparison of the preceding tables that the fixation of nitrogen is far in excess of that of potash in every instance except soil No. 292, which is the highest in magnesia content. The fixing power of the four soils in the series agrees more closely than in the potash series, but in each instance the clay soil fixed the least. Attention is called to soils Nos. 428, 448, and 474, which absorb much more nitrogen than potash. In case of two of the soils (428 and 474) this may be accounted for by the high content of organic matter. In the last two, fractions of percolate nitrates and nitrites were determined and both were found to be present in one case to the extent of 14.4 parts per million N as NO_3 and 3.1 parts per million N as NO_2. This indicates the rate at which nitrification was going on at the close of the experiments.

As in the potash series, the highly basic soils fixed much more nitrogen at the beginning of the experiments and a much larger total amount than the less basic. On the other hand, the decrease in fixing power was much slower and more gradual in the other soils.

SODIUM NITRATE.

Of the salts commonly used as fertilizing materials all are strongly fixed by the soil except nitrates. However, nature has made a wise provision for retaining nitrogen in an insoluble form, which becomes slowly available for growing plants. Determinations of the amount of nitrate nitrogen removed from the original soils gave the following results:

Nitrate nitrogen removed from the soils by distilled water.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100	4.2	8.6	5.9	106
200	2.4	.0	.0	2
300	.0	.0	.0	.4

These data indicate a condition found to be true in all soils, namely, the readiness with which nitrates are leached from the soil by rains. Soil No. 474 is a very porous, floury soil, containing a high percentage of organic matter, and under the existing climatic conditions would be expected to have a high nitrate content.

The following table shows the absorbing power of these soils for nitrate nitrogen, using a solution of sodium nitrate which contained 250 parts per million of nitrogen:

Absorption of nitrogen from a solution of $NaNO_3$.

[Expressed in parts per million of nitrogen in the percolate.]

Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.	Percolates of 100 cc. each.	Soil No. 292.	Soil No. 448.	Soil No. 428.	Soil No. 474.
100..........	147	157	142	290	1,000.........	240	225	230	195
200..........	184	162	180	170	1,100.........	240	230	230	185
300..........	215	190	180	200	1,200.........	230	235	235	215
400..........	245	240	205	235	1,300.........	240	235	240	215
500..........	240	245	225	235	1,400.........	245	240	240	215
600..........	225	220	220	200	1,500.........	250	245	250	220
700..........	205	205	215	195	1,600.........	250	250	250	225
800..........	230	240	215	220	1,700.........	250	250	250	....
900..........	230	225	225	175	1,800.........	250	250	....	....

Summary of above table.

Soil No.	Nitrogen added to 100 gm. soil.	Nitrogen fixed by 100 gm. soil.	Per cent of nitrogen fixed.
	Gram.	*Gram.*	
292..	0.4500	0.0384	8.5
448..	.4500	.0456	10
428..	.4250	.0518	12
474..	.4000	.0610	15

The above table presents some very interesting data. It is quite generally conceded that soils have no fixing power for nitrates and for this reason it is difficult to explain the action of soil No. 474 toward this salt. The percolation was very slow in this instance and the rate decreased to such an extent that the series had to be stopped after 1,600 cubic centimeters had passed through, as the solution would no longer filter through the column. This condition exists in spite of the fact that the soil contained only an extremely small percentage of clay. Soil No. 428 acted somewhat similarly, but percolation did not stop completely as in the case of No. 474. This condition is undoubtedly brought about by the action of sodium nitrate upon the organic matter, as both of these soils were high in this constituent. Soil No. 474 was apparently still fixing nitrogen at the close of the experiment, as in no case except with the first 100 cubic centimeters did the percolate reach a concentration of 250 parts per million. These figures indicate that while soils are unable to retain nitrates against the action of nitrate-free water, they are able to retain limited amounts against the action of water with a high nitrate content. It is possible that considerable denitrification took place in soil No. 474. The sluggish movement of the solution through this soil indicates the existence of just the conditions which are conducive to denitrification. The same is true of No. 428.

Denitrification refers, of course, to any transformation which nitrates may undergo, such as its conversion into nitrate, ammonia, free nitrogen, or protein.

ABSORPTION OF FERTILIZER SALTS BY FRESH AND AIR-DRIED SOILS.

The type of soil occurring in greatest abundance on the islands is a highly ferruginous red clay (No. 517). For this reason it was decided to make a series of percolations using both soil and subsoil of this type in the fresh and air-dry condition, using sodium nitrate, ammonium sulphate, potassium phosphate, and calcium phosphate.

The fresh soil contained 19.7 per cent moisture; the fresh subsoil, 24.4 per cent moisture.

The method employed was essentially the same as that used in the previous series except that it was found to be necessary to use only 50 grams of soil with the phosphates in order to effect a passage of the solution through the soil column. Also the concentration of the solution was increased in an attempt to saturate the soil with phosphates. Determinations were made of the solubility in distilled water of the phosphate in the saturated soil, and it was found to be negligible. On passing distilled water through a column of 50 grams of soil and determining the percentage of phosphoric acid in each 100 cubic centimeters passing through, only a faint trace was detected.

ABSORPTION OF PHOSPHORIC ACID.

The following table shows the absorbing power of the red clay soil for phosphoric acid when applied as monopotassium phosphate:

Absorption of phosphoric acid from a solution of KH_2PO_4.

[Expressed in parts per million of PO_4 in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
PO_4 IN SOLUTION, 800 PARTS PER MILLION.									
100	44	72	Trace.	Trace.	400	180	260	24	32
200	38	128	21	27	500	220	340		
300	124	165	22	29	600	290	340		
PO_4 IN SOLUTION, 1,400 PARTS PER MILLION.									
500			150	290	1,300	950	850		
600			325	325	1,400	900	825		
700	410	460	350	360	1,500	750	750		
800	390	460	560	665	1,600	750	750		
900	400	500	675	675	1,700	725	600		
1,000	430	500	825	825	1,800	875	850		
1,100	530	400			1,900	675	675		
1,200	620	560			2,000	875	825		
PO_4 IN SOLUTION, 1,025 PARTS PER MILLION.									
1,500			700	700	2,800			950	950
1,750			675	675	3,250	600	600		
2,250			600	600	3,300			1,025	1,025
2,500	750	675			3,800	950	950		
2,725	675	675			4,300	1,025	1,025		

Summary of preceding table.

Soil.	PO_4 added to 100 gm. soil.	PO_4 fixed by 100 gm. soil.	Per cent of PO_4 fixed.
	Grams.	*Grams.*	
Fresh soil	9.5950	3.8062	39.6
Fresh subsoil	9.5950	3.8544	40.2
Air-dry soil	6.8350	2.7372	40.1
Air-dry subsoil	6.8350	2.6820	39.3

The absorption of phosphoric acid from monocalcium phosphate was as follows:

Absorption of phosphoric acid from a solution of $CaH_4(PO_4)_2$.

[Expressed in parts per million of PO_4 in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
SOLUTION CONTAINED 1,300 PARTS PER MILLION PO_4.									
100	210	210	203	203	400	700	650	700	703
200	470	490	750	700	500	1,012	1,012	...	...
300	615	585	625	800	600	925	1,200	...	...
SOLUTION CONTAINED 1,700 PARTS PER MILLION PO_4.									
500	...	...	775	775	1,300	1,100	1,100	...	...
600	...	...	850	850	1,400	1,200	1,150	...	...
700	1,300	1,275	1,250	1,100	1,500	1,350	1,400	...	...
800	825	950	1,000	1,000	1,600	1,350	1,250	...	...
900	900	950	1,100	1,250	1,700	1,350	1,250	...	...
1,000	1,100	1,100	1,025	1,000	1,800	1,250	1,325	...	...
1,100	1,100	1,100	850	975	1,900	925	925	...	...
1,200	950	950	1,300	1,275					
SOLUTION CONTAINED 2,812 PARTS PER MILLION PO_4.									
1,700	...	...	1,300	1,250	2,750	1,250	...	...	...
1,925	...	...	...	1,250	3,000	...	...	2,812	2,812
1,950	...	...	1,300	...	3,250	1,600	1,550	...	...
2,000	1,350	1,350	...	...	3,500	...	...	2,812	2,812
2,450	...	...	1,600	...	3,800	2,812	2,812	...	...
2,500	1,450	1,350	...	1,600	4,300	2,812	2,812	...	...
2,725	...	1,400	...	...					

Summary of above table.

Soil.	PO_4 added to 100 gm. soil.	PO_4 fixed by 100 gm. soil.	Per cent of PO_4 fixed.
	Grams.	*Grams.*	
Fresh soil	8.3328	5.9110	70.9
Fresh subsoil	8.3328	5.9880	71.8
Air-dry soil	6.9416	5.5232	79.6
Air-dry subsoil	6.9416	5.4732	78.8

The results in the above tables can be compared with those of the previous series only relatively, due to the fact that the solution in this case was so much more concentrated. They indicate the practical impossibility of saturating Hawaiian soils with phosphoric acid or adding an excess in a practical way. It will be noted that this type of soil is able to absorb nearly 4 per cent of its weight of phosphoric acid (PO_4) in the fresh soil and nearly 3 per cent in the air-dry soil from the potassium salt; also, that from the calcium salt the soil absorbed nearly 6 per cent of its own weight of phosphoric acid in the fresh soil and 5.5 per cent in the air-dry soil. It is difficult to explain the higher absorptive power of the fresh soil over the air dry, but it is probably due to the physical properties, and is related to the soil films.

This soil is composed of very fine particles, exposing relatively enormous surface to the action of the soil solution or any added salt solution. In the fresh soils of this type these particles are in a high state of deflocculation and the effect of drying in the air tends to flocculate them to a great extent, thereby reducing the area of the exposed surface. Drying would also tend to modify the film surrounding each particle. Even with only 50 grams of soil it was found impossible, due to the strong deflocculating action of the phosphate salts, to make the percolations in tubes, but funnels had to be used. The samples previously dried in the air percolated more slowly than the fresh soils. This is probably due to the fact that the soil swelled more in the tube after the addition of the solution, thus packing more closely and closing up the pore spaces.

There was apparently very little difference between the absorbing power of the soil and subsoil, but considerable variation between the fresh and air-dry soils. The rate of fixation in the early part of the experiment was considerably faster in the latter than in the former, and hence the air-dry soils were more quickly saturated by the salts. Another interesting fact is the difference in the absorptive power of this type of soil for phosphoric acid in the two forms. The data are sufficient to justify the statement that this difference is due to the reversion of the calcium salt, although due also in great part to the state of the iron and aluminum compounds which exist in this type of soil. The absorption from the potash salt was more complete at the first application, but thereafter decreased quite rapidly and regularly. It should also be noted that at the outset the air-dry soil absorbed the potash salt more completely than the fresh soil. This is thought to be due to the partial elimination of the film surrounding the soil particles, thus allowing the solution to penetrate more thoroughly.

ABSORPTION OF POTASH.

The strength of solution used in the potash series was the same as in the first series. One hundred-gram portions of soil were used. The results of extraction of the original soils are given in the following tables:

Removal of potash from soil by distilled water.

[Expressed in parts per million of K in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	40	32	64	32	400	52	84	27	23
200	17.4	14.8	52	36	500	68	16		
300	56	32	48	32	600	32			

The results of determinations of the absorption of potash from potassium sulphate are given in the following table:

Absorption of potash from a solution containing 204 parts per million K from K_2SO_4.

[Expressed in parts per million in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	64	52	52	68	1,000	172	176	180	176
200	68	44	80	24	1,100	152	152	180	192
300	212	136	104	60	1,200			196	184
400	216	160	180	120	1,300			192	200
500	164	168	180	120	1,400	200	200	172	180
600	172	180	180	120	1,500	200	192	196	176
700	192	180	172	140	1,600	216	212	204	188
800	180	180	184	180	1,700	208	204	188	192
900	184	196	192	180	1,800			212	200

Summary of above table.

Soil.	K added to 100 gm. soil.	K fixed by 100 gm. soil.	Per cent of K fixed.
	Grams.	*Grams.*	
Fresh soil	0.3468	0.0468	13.5
Fresh subsoil	.3468	.0636	18.3
Air-dry soil	.3672	.0528	14.4
Air-dry subsoil	.3672	.0972	26.5

The effect of the potassium sulphate solution on the solubility of lime and magnesia is shown in the following table:

Effect of potassium sulphate solution upon the solubility of lime and magnesia.

[Expressed in parts per million in the percolate.]

Percolates of 100 cc. each.	Lime (CaO).				Magnesia (MgO).			
	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	60	38	62	50	34	28	34	30
300	50	64	38	54	56	56	18	20
600	44	34	62	52	20	20	20	20
1,700	24	16	20	24	18	12	14	12

These tables indicate that the potash in this type of soil is quite soluble. The fixing power of this soil is far below that of the four soils used in the previous series; that is, the red clay soil of the islands is more easily saturated with potash than the other types. This is partly due to the low lime and magnesia content of this soil. The two series illustrate quite well the effect of these bases upon the fixation of potash. The figures in the table on page 19 indicate the subsoil to have the power of fixing more potash than the soil, and that drying in the air tends to increase this power.

ABSORPTION OF NITROGEN.

AMMONIUM SULPHATE.

This series was carried through similarly to the previous ammonium sulphate series. A table showing the solubility in distilled water of the ammonia nitrogen in the original soil is given herewith:

Ammonia nitrogen removed from the soil by distilled water.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	5.1	Trace.	7.47	5.04
200	Trace.	Trace.	11.16	6.1
300	Trace.	Trace	Trace.	7.2

This type of soil is shown to contain only small amounts of ammonia nitrogen soluble in water, the amounts being slightly lower than those found in the previous series.

The following table shows the absorbing power of this soil for ammonium nitrogen:

Absorption of nitrogen from a solution of $(NH_4)_2SO_4$.

[Expressed in parts per million in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
SOLUTION CONTAINED 246 PARTS PER MILLION NITROGEN FROM $(NH_4)_2SO_4$.									
100	26.5	17.8	12.5	25.2	700	151.3	157.1	188	172
200	65.2	54.9	113.2	111	800	192.9	178.6	180	172
300	71.6	66.6	178.2	145.6	900	178.6	152.3	206	184
400	185	143	162.3	149.6	1,000	239	204	188	184
500	181.3	183.3	165.1	168.9	1,100	224	242	224	214
600	211.5	167.4	172	160					
SOLUTION CONTAINED 204 PARTS PER MILLION NITROGEN FROM $(NH_4)_2SO_4$.									
1,200	181.4	182.6	224	214	1,400	212	212	206	206
1,300	211.6	200	206	206					

Summary of preceding table.

Soil.	Nitrogen added to 100 gm. soil.	Nitrogen fixed by 100 gm. soil.	Per cent of nitrogen fixed.
	Gram.	*Gram.*	
Fresh soil	0.3318	0.1000	30.1
Fresh subsoil	.3318	.1164	35
Air-dry soil	.2706	.0916	33.9
Air-dry subsoil	.2706	.1019	37.6

Since ammonium salts are retained by the soil in most respects by the same reactions which govern the absorption of potash, we would expect the red clay soil to have the low absorptive power shown in the above table, which is less than one-half that of the soils used in the previous series. The subsoil showed a slightly higher fixing power than the soil, while the effect of drying in the air was to reduce the fixing power. This latter finding is just the reverse of that obtained in case of potash.

SODIUM NITRATE.

The absorbing power of this soil for sodium nitrate is very much lower than that of the other types, as may be seen from the following tables:

Removal of nitrate nitrogen from soil by distilled water.

[Expressed in parts per million of nitrogen in the percolate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	19.2	8.8	12.8	7.2
200				

Absorption of nitrogen from a solution of 250 parts per million nitrogen from $NaNO_3$.

[Expressed in parts per million of nitrogen in the filtrate.]

Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.	Percolates of 100 cc. each.	Fresh soil.	Fresh subsoil.	Air-dry soil.	Air-dry subsoil.
100	187.5	180.0	215.0	215.0	300	250.0	250.0	250.0	250.0
200	250	255	240	240	400	250	250	250	250

Summary of above table.

Soil.	Nitrogen added to 100 gm. soil.	Nitrogen fixed by 100 gm. soil.	Per cent of nitrogen fixed.
	Gram.	*Gram.*	
Fresh soil	0.1000	0.0062	6.2
Fresh subsoil	.1000	.0065	6.5
Air-dry soil	.1000	.0045	4.5
Air-dry subsoil	.1000	.0045	4.5

The above results show the low fixing power of this type of soil for nitrates. This fact strongly indicates the rôle of organic matter in the absorption of this salt. The organic matter content of the previous series of soils was much higher than that of the red clay. There was apparently no difference between the fixing power of the soil and the subsoil, but it was stronger in the fresh than in the air-dried samples.

ABSORPTION OF FERTILIZER SALTS WHEN APPLIED IN MIXTURES, AND THE EFFECT OF HEAT AND ANTISEPTICS.

A third series of experiments was made with the idea in mind of applying a solution containing a mixture of fertilizer salts and at the same time determining the effect of heat and volatile antiseptics upon the absorbing power. The soils chosen for this series were No. 428, a highly organic soil used in the first series, and No. 517, the red clay soil used in the second series. Three fertilizer mixtures were used and applied to the soil in series of three, namely, untreated, heated (230° C. in air bath), and partially sterilized (5 cubic centimeters chloroform to 100 grams soil kept in a closed fruit jar 48 hours, then spread out in the air 24 hours before placing in the glass tubes). The mixtures were as follows: (1) ammonium sulphate, potassium phosphate, and potassium sulphate; (2) ammonium sulphate, calcium phosphate, and potassium sulphate; and (3) sodium nitrate, calcium phosphate, and potassium sulphate. The solutions were allowed to percolate through the soil at the rate of 100 cubic centimeters in 24 hours, and the percolates were analyzed.

ABSORPTION OF PHOSPHORIC ACID.

The table following shows the fixing power of these soils for phosphoric acid when applied in mixtures.

Absorption of calcium and potassium phosphate in solutions of fertilizer mixtures.

[Expressed in parts per million of PO_4 in the percolate.]

Percolates of 100 cc. each.	Soil No. 517.								
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	Trace.	46	26	26	38	44	224	50	280
200	86	34	34	50	120	380	360	56	400
300	140	22	100	392	512	448	232	328	256
500	200	70	240	550	650	700	600	550	750
700	480	360	460	1,700	1,550	1,750	1,050	1,050	1,050
900	168	Trace.	200	1,600	1,700	1,650	1,400	1,350	1,350
1,100	480	420	540	1,750	1,750	2,000	1,400	1,050	1,450
1,300	480	460	540	1,600	1,650	1,850	1,350	1,100	1,400
1,500	540	540	680	1,700	1,750	1,750	1,250	1,500	1,550
1,700	480	500	500	1,500	1,800	1,700	1,500	1,150	1,150
1,900	580	640	640	1,950	1,950	2,000	....	....	....
2,100	560	560	660	1,950	2,000	2,000	....	....	....

SUMMARY.

PO_4 added to 100 grams soil, grams.	1.5750	1.5750	1.5750	4.3050	4.3050	4.3050	2.8050	2.8050	2.8050
PO_4 fixed by 100 grams soil, grams.	.7588	.8548	.6670	1.3982	1.2780	1.0678	1.6134	1.2116	1.5014
Per cent of PO_4 fixed	48.2	54.3	42.3	32.5	29.7	24.7	57.3	43.2	53.5

Percolates of 100 cc. each.	Soil No. 428.								
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	Trace.	20	Trace.	19	15	Trace.	21	30	26
200	16	13	20	16	15	15	15	14	20
300	16	13	20	16	15	15	15	14	20
500	12	12	12	11	10	11	11	10	12
700	33	16	15	16	8	15	20	28	28
900	19	9	14	21	36	6	19	9	8
1,100	19	90	19	6	6	9	8	5	8
1,300	18	236	20	8	19	8	8	6	10
1,500	7	236	6	6	15	8	7	5	8
1,700	11	264	21	9	33	12	....	....	....
1,900	22	240	21	17	36	18	....	....	....
2,100	31	320	16	13	70	14	....	....	....

SUMMARY.

PO_4 added to 100 grams soil, grams.	1.4700	1.4700	1.4700	0.8265	0.8265	0.8265	0.6375	0.6375	0.6375
PO_4 fixed by 100 grams soil, grams.	1.4296	1.1104	1.4298	.7995	.7754	.8033	.61.78	.6191	.6161
Per cent of PO_4 fixed	97.1	75.5	97.1	96.8	93.9	97.3	96.9	97.3	96.7

The solution used in the first series of three, columns 1, 2, and 3, contained 750 parts per million PO_4 from potassium phosphate; 4, 5, and 6, 2,050 parts per million PO_4 from calcium phosphate; 7, 8, and 9, 1,650 parts per million PO_4 from calcium phosphate; 10, 11, and 12, 700 parts per million PO_4 from potassium phosphate; 13, 14, and 15, 435 parts per million PO_4 from calcium phosphate; 16, 17, and 18, 425 parts per million PO_4 from calcium phosphate. The solution used with soil No. 428 was made up to a much weaker strength for the reason that it would be more comparable with the results obtained on this soil given in the first series.

The absorbing power of the red clay soil was appreciably less for phosphates in mixtures, but that of the highly organic soil is very much the same, regardless of method of application. The effect of heat or antiseptics was not striking, but in most instances caused a decrease in the fixing power. In one instance, namely, with the highly organic soil, the heat caused a decided decrease in fixing power.

ABSORPTION OF POTASH.

The results obtained with the application of potash in mixtures are shown in the following table:

Absorption of potash from a solution of fertilizer mixtures.

[Expressed in parts per million K in the percolate.]

Percolates 100 cc. each.	Soil No. 517.								
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	196	180	268	172	120	156	108	112	144
200	348	316	300	152	132	88	104	132	108
300	440	440	376	44	80	72	176	104	68
500	484	460	480	88	84	64	84	120	108
700	544	508	552	188	224	228	216	232	140
900	540	580	524	164	260	276	204	228	208
1,100	540	584	572	124	216	200	180	188	232
1,300	564	576	588	184	288	204	256	180	132
1,500	544	560	504	156	224	176	228	236	172
1,700	544	576	528	152	244	140	156	360	280
1,900	488	564	544	196	188	216	284	....	288
2,100	428	528	496	164	192	184	212	368	248

SUMMARY.

K added to 100 grams soil........grams..	1.0038	1.0038	1.0038	0.3570	0.3570	0.3570	0.4536	0.4536	0.4536
K fixed by 100 grams soil........grams..	....	....	....	....	....	....	....	....	....
Per cent of K fixed.	....	....	....	....	....	....	....	....	....

Absorption of potash from a solution of fertilizer mixtures—Continued.

Percolates of 100 cc. each.	Soil No. 428.								
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	96	432	112	96	272	118	148	268	104
200	168	432	192	104	192	104	76	192	72
300	300	520	292	144	188	140	112	224	112
500	360	516	400	212	220	192	192	240	180
700	416	552	428	216	268	248	204	228	188
900	420	572	432	184	224	196	192	220	216
1,100	368	608	412	224	224	216	188	228	188
1,300	416	620	424	212	180	180	188	200	192
1,500	416	580	408	232	200	192	240	292	252
1,700	456	620	460	212	220	224			
1,900	424	600	448	228	212	200			
2,100	432	524	448	224	236	236			

SUMMARY.

K added to 100 grams soil.......grams..	1.2264	1.2264	1.2264	0.3822	0.3822	0.3822	0.3090	0.3090	0.3090
K fixed by 100 grams soil.......grams..	.9468		1.0224						
Per cent of K fixed.	77.6		83.6						

The above table presents some striking results, and indicates that Hawaiian soils possess a very low fixing power for potash when applied with phosphates, especially calcium phosphate. In every instance, except two, the amount of potash found in the filtrate was greater than the weight added to the soil. This is undoubtedly due partly to a replacement of the potash by lime. The effect of heat in case of the highly organic soil was to considerably reduce the fixing power, but chloroform reduced it only slightly. With the red clay soil there was very little variation, due to sterilization either with heat or antiseptics. This was contrary to the results obtained when potash was used alone. Drying in the air increased the fixing power.

The solutions used on samples reported in columns 1, 2, and 3 contained 478 parts per million K from K_2SO_4; 4, 5, and 6, 170 parts per million; 7, 8, and 9, 216 parts per million; 10, 11, and 12, 584 parts per million; 13, 14, and 15, 182 parts per million; 16, 17, and 18, 206 parts per million.

ABSORPTION OF NITROGEN.

AMMONIUM SULPHATE.

The following table shows the results obtained by the application of ammonium sulphate in mixtures:

Absorption of nitrogen from a solution of ammonium sulphate in a mixed fertilizer.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Soil No. 517.					
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	81.5	188.4	88.9	64.9	133.9	91.3
200	128.8	148.6	....	125.4	167.2	168.7
30	99	138	111	135	144	114
500	130	133	128	148	143	153
700	131	130	129	168	128	136
900	137	174	136	156	159	156
1,100	149	141	151	153	151	164
1,300	178	166	178	175	170	163
1,500	178	178	178	159	159	172
1,700	172	172	172	172	172	172
1,900	....	....	....	....	....	....

SUMMARY.

Nitrogen added to 100 grams soil ....gram..	0.1892	0.1892	0.1892	0.1892	0.1892	0.1892
Nitrogen fixed by 100 grams soil ....do....	.0342	.0152	.0350	.0268	.0194	.0231
Per cent of nitrogen fixed	18.1	8.03	18.5	14.2	10.2	12.2

Percolates of 100 cc. each.	Soil No. 428.					
	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	66.2	154.5	44.9	86.1	140.7	81.5
200	88.2	116.9	103.6	108	128	112
300	89	112	93	110	122	107
500	109	109	103	123	154	116
700	120	136	107	118	133	112
900	103	116	110	149	146	122
1,100	90	139	114	148	134	144
1,300	118	157	147	176	162	145
1,500	147	172	159	187	172	178
1,700	147	172	147	172	172	172
1,900	172	187	172	187	187	187

SUMMARY.

Nitrogen added to 100 grams soil ....gram..	0.2064	0.2064	0.2064	0.2064	0.2064	0.2064
Nitrogen fixed by 100 grams soil ....do....	.0668	.0322	.0618	.0358	.0257	.0437
Per cent of nitrogen fixed	32.4	15.6	29.9	17.3	12.5	21.2

The very concordant results in the above table add proof to the theory that the fixation of ammonium nitrogen and potash are strikingly similar. The fixing power of the soils was far less for the nitrogen of ammonium sulphate in mixtures than when used alone. It was found that the heat decreased the fixing power of the soil greatly, while chloroform had a very slight effect.

All solutions used in this series contained 172 parts per million nitrogen from ammonium sulphate.

SODIUM NITRATE.

The following table gives the results of applying sodium nitrate in mixtures:

Absorption of nitrogen from a solution of sodium nitrate in a mixed fertilizer.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Soil No. 517. Sodium nitrate, calcium phosphate, and potassium sulphate.			Soil No. 428. Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
100	225	220	245	190	190	185
200	210	210	200	160	215	110
300	210	215	200	175	220	145
500	165	210	170	190	225	220
700	215	215	215	215	215	215

SUMMARY.

Nitrogen added to 100 grams soil...gram..	0.1075	0.1075	0.1075	0.1075	0.1075	0.1075
Nitrogen fixed by 100 grams soil....do....	.0060	.0010	.0085	.0145	.0010	.0200
Per cent of nitrogen fixed	5.6	0.9	7.9	13.5	0.9	18.6

The solutions used contained 215 parts per million nitrogen from nitrates, and, as was to be expected, the soils absorbed only extremely small amounts. The fixing power was shown to be very much less when this salt was applied in mixtures than when applied alone. the effect of heat was to decrease the fixing power, while the effect of chloroform was to produce a decided increase in fixing power. The latter is probably due to the sterilizing effect of the antiseptic upon the organisms present.

REMOVAL OF ABSORBED SALTS.

At the conclusion of the preceding series distilled water was allowed to percolate through the tubes at the rate of 100 cubic centimeters in 24 hours. In every 100 cubic centimeters of the solution after the first thus obtained phosphoric acid, potash, and nitrogen were determined.

REMOVAL OF ABSORBED PHOSPHATE.

In the following table will be found the results showing removal of absorbed phosphoric acid by distilled water from soil No. 517:

Absorbed phosphoric acid removed from soil.

[Expressed in parts per million PO_4 in the percolate.]

Percolates of 100 cc. each.	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
200	425	425	375	625	500	625	425	500	550
300	350	350	250	525	325	400	300	350	325
400	550	425	450	700	650	700	525	500	650
500	425	350	475	475	475	825	475	525	....
600	325	400	400	325	325	200	300	300	300
700	300	375	425	450	350	350	300	300	300
800	145	125	100	150	135	140	390	160	190
900	115	100	100	135	120	120	120	145	125
1,000	140	110	100	110	120	120	120	100	110
1,100	44	96	96	96	96	96	96	96	96
1,200	36	64	64	88	88	82	82	82	82
SUMMARY.									
PO_4 fixed......gm..	0.7588	0.8548	0.6670	1.3982	1.278	1.0678	1.6134	1.2116	1.5014
PO_4 removed..gm..	.2855	.2820	.2835	.3679	.3184	.3658	.3133	.3058	.3008
Per cent of PO_4 removed..........	37.7	33.1	42.4	26.4	25.	34.1	19.4	25.2	20.0

The above results show that the concentration of phosphate in the percolate decreased quite rapidly, approaching a constant. Apparently the potash salt was less strongly fixed as the precentage removed is greater than the calcium salt.

REMOVAL OF ABSORBED POTASH.

In the following table will be found the results showing removal of absorbed potash by distilled water from soil No. 517:

Removal of absorbed potash.

[Expressed in parts per million K in the percolate.]

Percolates of 100 cc. each.	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.			Sodium nitrate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
200	204	56	108	48	44	32	44	60	44
300	115	84	96	36	32	48	36	56	40
400	112	80	104	40	44	40	40	56	36
500	108	72	96	40	32	48	68	44	52
600	96	52	68	16	16	16	20	32	20
700	96	84	92	52	40	32	36	44	36
800	72	52	68	28	48	....	....	....	28
900	76	72	64	40	56	44	36	44	32
1,000	76	48	56	32	40	16	12	28	20
1,100	48	44	60	20	40	16	20	24	20
1,200	68	68	68	24	32	24	32	32	20
SUMMARY.									
K removed....gm..	0.1072	0.0712	0.0880	0.0376	0.0424	0.0316	0.0344	0.0420	0.0348

The above table adds further proof toward indicating the small amounts of potash absorbed by this type of soil when added in mixtures. (See also p. 25.) There is little decrease in concentration of the percolate with regard to this element.

REMOVAL OF ABSORBED NITROGEN.

In the following table will be found the results showing removal by distilled water of nitrogen absorbed from ammonium sulphate from soil No. 517:

Removal of absorbed nitrogen.

[Expressed in parts per million nitrogen in the percolate.]

Percolates of 100 cc. each.	Ammonium sulphate, potassium phosphate, and potassium sulphate.			Ammonium sulphate, calcium phosphate, and potassium sulphate.		
	Untreated.	Heated.	Chloroform.	Untreated.	Heated.	Chloroform.
200	73	68	66	84	73	73
300	51	44	44	46	38	40
400	46	39	42	28	25	22
500	42	30	33	18	13	10
600	31	20	22	7	9	....
700	25	17	22	7	7	3
800	21	16	18	4	6	3
900	16	16	16	3	5	3
1,000	21	16	21	11	9	6
1,100	21	16	18	3	4	2
1,200	13	16	11	2	4	2

SUMMARY.

Nitrogen fixed gm.	0.0342	0.0152	0.0350	0.0268	0.0194	0.0231
Nitrogen removed gm.	.0360	.0298	.0313	.0213	.0193	.0164
Per cent of nitrogen removed	....	....	89.5	79.6	99.4	71.0

The above table discloses the peculiar fact that practically all the nitrogen fixed by the soil from ammonium sulphate was removed by passing a liter of water through it. The concentration of the solution tended to decrease toward a constant value, as was the case with all the other elements of plant food.

SUMMARY.

The data presented in the foregoing pages throw considerable light upon the behavior of fertilizer salts in Hawaiian soils. They show the variation in absorbing power with the variation in soil types and composition of fertilizer added. Hawaiian soils have resulted from the degradation of lava rocks, some of which have subsequently been changed through the addition of coral limestone or submergence by the sea. Therefore they would naturally be expected to be of a highly basic nature, and to yield a highly basic soil solution, depending upon the absorptive power of the soil. Some of the soils have been

subjected to dense tropical plant growth, resulting in the accumulation of high percentages of humus, which has been shown in the previous tables to affect materially the absorbing power. Furthermore, the data indicate that the concentration of the soil solution does not depend primarily upon the solubility of the mineral constituents, nor the amount of fertilizer added, but upon the absorbing power of the soil.

As was expected, the fixation of phosphoric acid was much higher than the other elements. This is due to the highly basic character of the soils, and especially to the large amounts of iron, aluminum, and titanium present. It has been found in recent pot experiments with this type of soil that crops respond most readily to soluble phosphates—namely, sodium phosphate and acid phosphate. There was considerable difference in the physical action of calcium and potassium phosphates, the latter having a decided deflocculating action upon the clay, while the calcium salt filtered through the soil column perfectly clear. This, coupled with the results of the pot experiments cited above, indicates that absorbed sodium and potassium phosphates are not insoluble, but diffuse more readily and are more easily available for the growing plants. This indicates that phosphate should be applied to Hawaiian soils in the soluble form, and the best time for application is just before planting, not on account of any danger of loss through drainage, but through the danger of a slight decrease in availability, due to reversion.

Apparently the controlling factors in the fixation of potash are the amounts of lime and magnesia present. This is very clearly shown in the above tables, and the soils used in the experiments were good examples with which to illustrate this point. The fixing power for this element, while not so strong as for the phosphoric acid, is quite marked. However, it should not be applied in too large quantities, nor too often, as it is quite readily leached from the soil by rains and irrigation.

The fixation of ammonium nitrogen, as already mentioned, is controlled by the same general factors which govern the absorption of potash. But the point of saturation is in most cases above that of the potash. However, it is not so strongly fixed and is leached out quite readily by the rains and drainage water. Some investigators claim that ammonia replaces the bases combined with the complex "humates," and, if so, this accounts for the soils in the first series having such a high fixing power both for potash and ammonium nitrogen, while the red clay soil was strikingly lower.

The power of the soil for fixing nitrate nitrogen is almost negligible, except in case of the highly organic soils. Apparently the organic

matter reacted with the nitrate solution, as the effect of this solution on the soil was quite marked.

The series showing the relation of the fixing power of soil and subsoil, and the effect of drying in the air, gave only slight differences. It was found, however, that phosphoric acid was fixed more strongly by the fresh soil, but there was scarcely any difference between the soil and subsoil. This is probably due to the fact that there is little, if any, difference in the mechanical condition of soil and subsoil in this red clay type, and also very little difference in chemical composition. The fixation of potash was higher in the air-dried soil, as previously explained, and higher in the subsoil than the soil. The ammonium nitrogen, strange to say, unlike the potash, was more strongly fixed by the fresh soil, which indicates the possibility of certain organisms affecting the fixation. The subsoil had a higher fixing power than the soil. There probably are also organisms acting as fixing agents for the nitrates, as the fresh samples had a higher fixing power than the air dry, while there was no difference in that of the soil and subsoil.

The most striking results are those obtained from the series in which a solution of mixed fertilizer was used. From the data at hand the conclusion is thought justified that the least waste is to be had by application of fertilizer salts singly rather than in mixtures. When the salts were applied singly there was a marked loss of potash, a decrease in amount of ammonium nitrogen fixed, a decrease in nitrate nitrogen, and a decrease in phosphates in case of the red clay, but scarcely any difference with the organic soil. However, there was no deflocculation of the soil when the salts were added in mixtures, except to a small extent in the mixtures which contained potassium phosphate. In this instance the percolates came through cloudy—that is, they contained deflocculated clay. On the other hand, the extracts in which the calcium salt was used were perfectly clear and colorless. Again, all the percolations proceeded quite rapidly, while several of the salts, the phosphates in particular, when used alone, would not allow a solution to pass through a column of soil. Solutions containing potassium phosphate percolated more slowly than those containing calcium phosphate.

The effect of heat and antiseptics was not very striking and the results were not very consistent. In one instance, a highly organic soil, heat decreased the fixing power for phosphoric acid, while in general it decreased the fixing power for potash, ammonium nitrogen, and nitrate nitrogen. The effect of chloroform on the fixation of the first three elements was negligible, while it increased the fixing power for nitrates.

The removal of the absorbed elements approached quite rapidly a constant in the case of the potash and ammonium salts, but more slowly in that of the phosphates. This was due to the excessive amounts of this constituent which had been added. By reference to tables on pages 5 and 8 it will be seen that when phosphates were added to the soil in light applications the concentration of the solution remained practically unchanged for an indefinite period.

ACKNOWLEDGMENTS.

Acknowledgments are due and thanks are hereby extended to Dr. W. P. Kelley for valuable suggestions and for interest shown throughout this investigation.

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J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 37.

AMMONIFICATION AND NITRIFICATION IN HAWAIIAN SOILS.

BY

W. P. KELLEY,

Chemist.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

WALTER H. EVANS, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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[1] Resigned October 27, 1914.

LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *January 10, 1914.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 37 of the Hawaii Agricultural Experiment Station, a paper on Ammonification and Nitrification in Hawaiian Soils, prepared by Dr. W. P. Kelley, chemist of the station. The nitrogen compounds which occur in soils and the modifications which they undergo are of great importance in practical agriculture. In many Hawaiian soils the conditions which influence the form and changes of these compounds are somewhat unusual. A study of the factors which modify ammonification and nitrification is therefore of great scientific and practical importance. It is believed that a distinct contribution to the knowledge of these processes and also to an understanding of the significance of the lime-magnesia ratio, particularly as it is related to changes in the nitrogen compounds of the soil, is made in this bulletin.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

CONTENTS.

AMMONIFICATION AND NITRIFICATION IN HAWAIIAN SOILS.

INTRODUCTION.

The importance of bacteria in soils has become generally recognized. In contrast to the extreme chemical view formerly held it is now believed that the biological activities going on in soils are of more fundamental importance, and that as a result of bacterial action the minerals become more soluble and chemical transformations are brought about in the organic and inorganic constituents.

Soils, therefore, are no longer looked upon as dead reservoirs of plant food, but, on the contrary, as teeming with organized life. Various chemical substances, the degree of porosity, the moisture content, and other factors, all exert important influence on the activity of soil organisms. For these reasons the application of fertilizers, tillage, crop rotation, etc., directly affect the soil organisms, and therefore, indirectly, the chemical changes. But the real seat of bacterial action is the organic matter, and it is this part of the soil that undergoes the greatest change as a result of their action.

Practically all organic substances occurring in soils undergo decomposition to some degree with the consequent formation of a great variety of chemical compounds, principally organic in nature. Some of these products exert marked chemical action on the mineral constituents; certain of them are toxic both to the higher plants and to the bacteria themselves, while others serve as nutrients to the higher plants. In the end, however, these become converted into carbon dioxid, water, ammonia, nitrate, free nitrogen gas, etc.

Phases of soil bacteriology which have received a great amount of attention are ammonification and nitrification. Soil nitrogen exists principally in complex, insoluble, protein-like combinations, in which form it is unavailable to the higher plants, but by the action of bacteria ammonia is split off, which then is oxidized to nitrate.

Formerly, much emphasis was placed on the numbers of organisms present in soils. More recently, however, it has been found that the physiological efficiency of the organisms in different soils varies so greatly that now it is more common to measure the products of their action on nitrogenous substances rather than to base conclusions on the number of organisms present.

In considering the various factors that influence the growth of crops in Hawaii, it is inevitable that attention should be turned to certain phases of the nitrogen question. In the first place, Hawaiian soils generally contain relatively large amounts of nitrogen, on the average at least twice as much as mainland soils. Nevertheless, enormous amounts of nitrogenous fertilizers are applied to the land now in cultivation, and in some instances it has been found very profitable to use nitrogenous fertilizers on soils which contain large amounts of nitrogen. The low availability of the nitrogen in the soils emphasizes the need of a better understanding of the bacterial processes going on.

In the second place, many Hawaiian soils contain very high percentages of clay and little gravel or sand, and, therefore, are very close textured; consequently aeration is poor. Such lands, especially when plowed for the first time, are exceedingly inert. In the pineapple section of Oahu it is necessary to allow the new lands to lie fallow, with occasional cultivation, for a period of several months after the first plowing before planting, but it has been found that the growth of crops is normal and satisfactory on the new lands immediately after plowing, where brush and other refuse had been burned. Heat, therefore, seems to accomplish the same effect as continued aeration.

In the third place, Hawaiian soils are extremely abnormal in mineral composition. Various substances, such as ferric and aluminum hydrate, the oxids of manganese, titanium compounds, etc., are present in large amounts. Besides, carbonates, except in a few localities, are present in extremely small amounts. It is commonly held that the presence of calcium carbonate is essential to successful crop production, for the reason that nitrification is believed to be dependent on it for the maintenance of neutral conditions. How far other bases can take the place of calcium carbonate is not fully known.[1] The relative and absolute amounts of lime and magnesia in Hawaiian soils vary greatly, but generally magnesium occurs in considerably larger amounts than calcium. The lime-magnesia ratio is a question of much interest among soil investigators at the present time, but the bearings of this ratio on bacterial action have not been thoroughly studied. In view of the large amounts of lime, some of which is highly magnesian in character, now being applied to soils, a study of ammonification and nitrification as affected by variations in this ratio is of general interest.

In the investigation reported in this bulletin the effects of certain factors on nitrification and ammonification have been studied, but many organic forms of nitrogen are also known to be available to the higher plants, and other factors frequently complicate the subject so

[1] See Ashby, Jour. Agr. Sci., 2 (1907), pp. 52–67.

as probably to render the nitrification process of less relative importance than has been frequently assumed. The nitrifying bacteria ar quite sensitive to lack of aeration, the presence of stagnant water, acidity, certain chemical substances, and the like, but there are instances in Hawaii in which the intensity of nitrification appears to bear no relation whatever either to the growth of crops or to the presence of chemical substances that are definitely poisonous to some agricultural crops. Hence the amount of nitrate and the intensity of nitrification in a soil should not be considered as forming adequate measures of the availability of nitrogen. The results obtained in nitrification and ammonification experiments, therefore, should be interpreted with caution, and every known condition and factor, as well as the crops to be grown, must be given due weight before anything like a satisfactory practical conclusion can be drawn.

AMMONIA AND NITRATE CONTENT OF UNCULTIVATED SOILS.

One of the first questions studied in this investigation has reference to the rates at which nitrification and ammonification take place in soils in situ. This is obviously important in establishing a basis for the comparison of different treatments and as offering some suggestion on the management of these soils. It is of special interest, moreover, for the indirect evidence furnished regarding the form of nitrogen that is probably utilized by the different plants growing on these soils.

While much study has hitherto been devoted to nitrification and ammonification in cultivated soils, so far as the writer has been able to find from literature at hand, very little investigation has been made on nitrification in sod lands, or soils lying long uncultivated. Certain references occur in the literature concerning the low nitrification going on in forest soils. Grandeau,[1] for instance, found no nitrate in certain forest soils, while Weis [2] reported considerable nitrate in the moor and forest soils of Denmark. Ritter [3] found little tendency toward nitrate formation in moor soils, as a rule, although he detected small amounts of nitrate in certain cases. Petit,[4] on the other hand, found pronounced evidence of nitrification in a decidedly acid forest soil deficient in lime. The nitrate content of peaty soils in America, on the other hand, is sometimes almost negligible. Jodidi [5] failed to detect nitrate in certain Michigan peats. It is generally known, moreover, that practically no nitrification takes place in the subsoils of humid climates.

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[1] Jour. Agr. Prat., n. ser., 13 (1907), pp. 645, 646.
[2] Forstl. Forsögsv., 2 (1908), No. 2, pp. 257-296.
[3] Internat. Mitt. Bodenk., 2 (1912), No. 5, pp. 411-428.
[4] Ann. Sci. Agron., 4. ser., 2 (1913), II, No. 4, pp. 397, 398.
[5] Michigan Sta. Tech. Bul. 4 (1909).

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In this investigation a wide range of moisture and other conditions were met with. Samples were drawn from pasture lands, submerged soils supporting a crop of rice and taro, similar lands left to dry but not cultivated after the crops had been harvested, forest and fern jungles, abandoned pineapple and cane fields, and the like. Some of the samples were drawn at times when the soil was almost air dry, while others were taken when the moisture content was near the optimum for plant growth. The plants growing on these soils represent a considerable range of species.

When possible the analyses were made immediately after taking the samples, so as to render unnecessary the use of antiseptics. Whenever the sample could not be analyzed immediately a few cubic centimeters of chloroform was added. Nitrate was determined by leaching 100-gram portions with water and then determining the nitrate dissolved by the use of the phenol disulphonic acid method; ammonia was determined by distilling 100-gram portions in copper flasks after adding magnesium oxid.

The results of determinations of nitrate and ammonia nitrogen in uncultivated soils by these methods are given in the following table:

Nitrate and ammonia nitrogen in uncultivated soils.

[Parts per million.]

Lab. No.		Crop and locality.	Nitrate nitrogen.	Ammonia nitrogen.
229	Soil	Pasture, Wahiawa	0.2	25.2
230	Subsoil	do	.2	19.6
233	Soil	do	.1	21.0
234	Subsoil	do	.1	11.2
235	Soil	do	.4	16.8
236	Subsoil	do	.2	14.0
273	Soil	Citrus orchard, station	.4	11.2
292	do	Rice, Waikiki	.5	2.0
293	Subsoil	do	3.0	7.0
300	Soil	Pasture, Kaneohe	Trace.	19.6
301	Subsoil	do	.0	11.2
302	Soil	Abandoned pineapple field, Kaneohe	.5	19.6
303	Subsoil	do	.7	16.0
306	Soil	Pasture, Kaneohe	.9	22.4
307	Subsoil	do	.3	15.4
310	Soil	do	.2	16.0
312	do	do	.1	21.0
313	do	Pasture and guava, Kaneohe	.4	26.6
315	do	Guava, Kaneohe	.3	18.2
328	do	Pasture, Kohala	1.3	12.6
330	do	Pasture, Wahiawa	1.3	14.0
334	do	Rice, Fort Shafter	.0	11.2
335	do	Coconut grove, Kailua	2.5	(1)
336	Subsoil	do	.7	(1)
337	Soil	Rice land, Kailua	15.0	(1)
338	Subsoil	do	5.7	(1)
341	Soil	Coffee, Maunawili	.5	(1)
342	Subsoil	do	2.2	(1)
417	Soil	Pasture Waipio	.4	7.7
449	do	Panicum, Glenwood	.6	14.0
450	do	Fern forest, Glenwood	.3	11.2
451	do	Sugar cane, Glenwood	.3	16.8
452	do	Fern forest, Glenwood	.2	26.6
454	do	do	.2	42.0
456	do	Sugar cane, Glenwood	.3	5.6
457	do	Pasture, Glenwood	.4	18.2
458	do	Ferns, etc., Glenwood	Trace.	30.8
486	do	Pasture, Kunia	6.0	(1)
488	do	Pasture, Wahiawa	1.6	(1)

[1] Not determined.

The very low nitrate content in all the samples examined with the exception of Nos. 337, 338, and 486 will at once be noted. Of these, No. 337 was taken in the Kailua district of Oahu from a rice field just after harvest, and, being a recently reclaimed tule marsh, the soil contains a high percentage of organic matter and is much more porous than the average island soil. No. 486 was taken from an old pasture in the Kunia district, near the lands now devoted to pineapples by the Hawaii Preserving Co. This soil is notably silty and is also much more porous than the island soils generally. Therefore all the uncultivated soils examined which contained any considerable amount of nitrate are porous and hence permit of considerable aeration without cultivation.

Not all the porous and organic soils in the island contain such amounts of nitrate when uncultivated. Nos. 449 to 458 are exceptionally well aerated soils, but none of these contained more than traces of nitrate. Climatic factors in this instance probably determine the low nitrate content. The samples were taken from the Hilo district of Hawaii where rainy weather prevails a large portion of the year, but when these soils are brought into warmer conditions nitrification has been found to set in.

The ammonia content of these soils, as shown in the table, is abnormally high, ranging from 2 to 42 parts per million. In general the ammonia content of soils elsewhere is much less than the nitrate content,[1] which is accounted for by the fact that the ammonia is nitrified almost as fast as it is formed. In Hawaiian soils, however, particularly where cultivation is not practiced, nitrification takes place very slowly, in many instances scarcely at all, which, as will be shown subsequently, is due to the lack of aeration. Ammonification, on the other hand, not being so dependent on aeration and also being less sensitive to other adverse conditions, goes on more or less uninterruptedly, with the result that ammonia accumulates to some extent.

As pointed out above, nitrification was formerly believed to be necessary to the growth of plants. Experiments are not wanting, however, which show that other forms of nitrogen can be assimilated. In a number of instances it has been found that ammonia and organic nitrogen compounds can be utilized as advantageously as nitrate. From the experiments of Müntz,[2] Laurent,[3] Griffiths,[4] Pitsch,[5] Hutchinson and Miller [6] and others, working under sterile conditions, it has been shown that ammonium compounds can be assimilated to a

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[1] Fraps found that some Texan soils also contain relatively large amounts of ammonia. Texas Sta. Bul. 106 (1908).

[2] Compt. Rend. Acad. Sci. [Paris], 109 (1889), p. 646.

[3] Ann. Inst. Pasteur, 3 (1889), p. 362.

[4] Chem. News, 64 (1891), p. 147.

[5] Landw. Vers. Stat., 34 (1887), pp. 217–258; 42 (1893), pp. 1–95.

[6] Jour. Agr. Sci., 3 (1909), pp. 179–194.

considerable extent by different plants. Moreover, Krüger[1] found that mustard, oats, and barley assimilate ammonia equally as well as nitrate, while potatoes prefer ammonia. From his experiments he concluded that nitrification is not so necessary for cultivated plants as has been supposed.

In 1910 [2] the writer showed that ammonia is greatly superior to nitrate in the nutrition of rice. It was found, for instance, that rice made very poor growth when nitrate was the only source of combined nitrogen present, but different ammonium compounds proved well suited to the plant. More recently Hutchinson and Miller [3] have shown that a considerable variety of organic nitrogen compounds can be assimilated and transformed into protein by peas. Certain organic nitrogen compounds, however, prove to be ill suited to the nutrition of peas.

Likewise, Schreiner et al.[4] have demonstrated that creatinin occurs in notable amounts in fertile soils, and is as valuable in the nutrition of wheat as nitrate.

From the data above submitted it is at once apparent that plants, growing on the uncultivated soils of Hawaii, must necessarily depend largely on forms of nitrogen other than nitrate, for not only is nitrate practically absent, but as will be shown subsequently, nitrification in many instances will not take place until aerated conditions have been maintained for a period of weeks; and the vigorous growth of practically all the uncultivated species in the islands and of such crops as rice, taro, and bananas, each of which is frequently grown under conditions which prevent nitrification, furnishes abundant evidence of the availability of the nitrogen present, and points conclusively to the dependence on forms other than nitrate.

Since ammonia nitrogen was found in these soils in considerable amounts, and ammonification can take place under the prevailing conditions, it seems justifiable to believe that ammonia is an important source of available nitrogen to the plants growing here, and that ammonification is of far greater importance than nitrification.

SOIL AERATION.

The importance of aeration in soils is generally recognized. In general, the degree of aeration depends upon the porosity and water content, and can be greatly increased by tillage. Notwithstanding the importance of oxygen in soils, and the fact that aeration stimulates bacterial action, the specific effects resulting from aeration are far from being adequately understood.

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[1] Landw. Jahrb., 34 (1905), p. 761.
[2] Hawaii Sta. Bul. 24.
[3] Jour. Agr. Sci., 4 (1912), pp. 282–302.
[4] U. S. Dept. Agr., Bur. Soils Bul. 83 (1911).

In view of the inactive state of nitrification in the uncultivated soils of Hawaii, considerable interest is attached to a study of the effects produced by aeration. This phase of the question has been taken up from two slightly different standpoints; first, with reference to the nitrate and ammonia content of soils cultivated without any special reference to the time and mode of tillage, and second, with reference to the possibility of the uncultivated soils containing agents that hinder nitrification.

The results of the determinations of nitrate and ammonia nitrogen in different cultivated soils are given in the following table:

Nitrate and ammonia nitrogen in cultivated soils.

[Parts per million.]

Lab. No.		Crop and locality.	Nitrate nitrogen.	Ammonia nitrogen.
274	Soil	Citrus orchard, station	10.0	11.2
288	....do	Corn, station	4.7	16.8
289	....do	....do	1.8	12.6
290	....do	Citrus orchard, station	14.5	15.4
291	Subsoil	....do	6.5	16.0
304	Soil	Pineapple, Kaneohe	10.0	12.6
305	Subsoil	....do	12.6	21.0
308	Soil	....do	17.0	19.6
317	....do	No crop, Kaneohe	15.4	12.6
319	....do	....do	9.7	18.2
326	....do	Corn, Kohala	19.0	15.4
327	....do	Pineapple, Kohala	10.0	12.6
329	....do	No crop, Waipio	75.0	33.6
331	....do	No crop, Helemano	32.0	28.0
332	....do	No crop, Fort Shafter	3.0	8.4
333	Subsoil	....do	1.5	6.4
339	Soil	No crop, Kailua	10.0	(1)
340	Subsoil	....do	5.0	(1)
416	Soil	Pineapples, Wahiawa	40.0	11.9
428	....do	Corn, Glenwood	7.2	64.0
455	....do	Lilies, Glenwood	4.7	21.0
459	....do	No crop, Glenwood	1.0	4.2
485	....do	Pineapples, Kunia	10.0	(1)
487	....do	Pineapples Wahiawa	10.8	(1)

[1] Not determined.

A comparison of the above data with that in the previous table indicates that, when aerated conditions are brought about in Hawaiian soils, nitrification generally becomes active. Ammonification was also stimulated by tillage. However, as previously stated, nitrification is at a low ebb in certain soils, although well aerated. The above table shows that soil No. 459 contained only one part of nitrate per million. This soil had been thoroughly tilled for several months and contained a large amount of organic matter. The low nitrification taking place here appears to be due to climatic factors rather than the absence of the nitrifying organisms and is being further investigated.

The composition of the mineral matters in the above soils varies enormously. No. 329 is highly manganiferous; No. 485 contains about 20 per cent titanic oxid; No. 288 contains a large excess of magnesia, while a majority of these soils are highly ferruginous, containing on the average about 20 per cent ferric oxid. Since the

nitrate content bears no definite relation to the amount of the abovenamed mineral constituents, and in a number of instances was equal to that found in soils elsewhere, it is safe to conclude that the abnormal mineral composition of Hawaiian soils does not prevent active nitrification and ammonification. The temperature being near the optimum for bacterial action greatly encourages nitrification when the other conditions are suitable.

AMMONIFICATION AND NITRIFICATION IN SOILS PREVIOUSLY UNCULTIVATED.

The inert character of the virgin soils of Hawaii has already been referred to. Moreover, heavy applications of various fertilizers, including nitrate, often fail to induce vigorous growth of pineapples on the new lands. In investigating this phenomenon, various treatments have been applied, including aeration for different lengths of time, the application of lime, burning, and partial sterilization. Large samples of soil were taken from uncultivated fields, and at the same time samples of corresponding soil cultivated at intervals for 10 months without having any crop growing thereon. At the time of sampling the nitrate and ammonia were as follows:

Nitrate and ammonia nitrogen in cultivated and uncultivated soils.

[Parts per million.]

Lab. No.	Condition.	Nitrate nitrogen.	Ammonia nitrogen.	Lab. No.	Condition.	Nitrate nitrogen.	Ammonia nitrogen.
329	Cultivated	75.0	33.6	417	Uncultivated	0.4	7.7
330	Uncultivated	1.3	14.0	487	Cultivated	10.8	(1)
416	Cultivated	40.0	11.9	488	Uncultivated	1.6	(1)

1 Not determined.

The above data again show that aeration greatly stimulates both nitrification and ammonification, and that the uncultivated soils contain an extremely low nitrate content.

EFFECTS OF BRIEF AERATION.

Further investigation of the effects produced by aeration led to a study of nitrification and ammonification at various intervals after the samples were drawn. The samples were divided into different portions. One of each was spread out in the laboratory to dry. The nitrate and ammonia were determined in these portions at intervals, as shown in the table following.

Effects of aeration on the content of nitrates and ammonia nitrogen in soils.

[Parts per million.]

Lab. No.	Condition when brought to laboratory.	Days after bringing to laboratory.	Nitrate nitrogen.	Ammonia nitrogen.	Lab. No.	Condition when brought to laboratory.	Days after bringing to laboratory.	Nitrate nitrogen.	Ammonia nitrogen.
329	Cultivated	None.	75.0	33.6	417	Uncultivated	315	0.5	50.4
329	.....do	28	160.0	56.0	485	Cultivated	None.	10.0	(1)
330	Uncultivated	None.	1.3	14.0	485	.....do	232	11.0	36.4
330	.....do	28	85.0	30.8	486	Uncultivated	None.	6.0	(1)
416	Cultivated	None.	40.0	11.9	486	.....do	232	5.0	40.6
416	.....do	14	57.5	12.5	487	Cultivated	None.	10.8	(1)
416	.....do	315	62.0	44.8	487	.....do	200	9.0	61.6
417	Uncultivated	None.	.4	7.7	488	Uncultivated	None.	1.6	(1)
417	.....do	14	.6	12.2	488	.....do	200	1.2	58.6

[1] Not determined.

During the drying out, ammonification took place to a considerable extent but at a more vigorous rate in the cultivated than in the uncultivated soils. Nitrification also took place in the cultivated soils, but with the exception of No. 330, was inactive in the uncultivated soils. The moisture content of these soils at the time of sampling was about one-half saturation, but, of course, rapidly decreased. Nevertheless, considerable nitrification took place in soils Nos. 329, 330, and 416 during the first three weeks.

The portions to be used in studying the effects produced by aeration for a brief time were thoroughly mixed upon reaching the laboratory, placed in large fruit jars, sterile water added in sufficient amounts to bring the moisture content to two-thirds saturation, then loosely covered with cotton plugs, and kept at from 27° to 30° C. in a dark closet. At various intervals portions were withdrawn with a sterile spatula, and the nitrate and ammonia determined. The results follow:

Ammonification and nitrification in soils after short periods of aeration.

[Parts per million.]

Lab. No.	Previous condition.	Days after taking from field.	Nitrate nitrogen.	Ammonia nitrogen.	Gain (+) or loss (−).	
					Nitrate nitrogen.	Ammonia nitrogen.
329	Cultivated	None.	75.0	33.6	....	....
329	.....do	14	140.0	42.0	+ 65.0	+ 8.4
329	.....do	32	220.0	22.4	+145.0	− 11.2
329	.....do	46	220.0	33.6	+145.0	.0
330	Uncultivated	None.	1.3	14.0	....	....
330	.....do	14	13.0	11.2	+ 11.7	− 2.8
330	.....do	32	14.6	11.2	+ 13.3	− 2.8
330	.....do	46	7.0	28.0	+ 5.7	+ 14.0
416	Cultivated	None.	40.0	11.9	....	....
416	.....do	14	70.0	19.6	+ 30.0	+ 7.7
416	.....do	28	92.0	14.0	+ 52.0	+ 2.1
416	.....do	42	90.0	28.0	+ 50.0	+ 16.1
417	Uncultivated	None.	.4	7.7	....	....
417	.....do	14	.6	22.4	+ .2	+ 14.7
417	.....do	28	13.0	42.0	+ 12.6	+ 34.3
417	.....do	42	12.0	42.0	+ 11.6	+ 34.3
485	Cultivated	None.	10.0	(1)	....	....
485	.....do	14	18.0	11.4	+ 8.0	....
485	.....do	28	27.5	18.2	+ 17.5	[2] + 6.8
485	.....do	42	31.5	7.0	+ 21.5	[2] − 4.4
485	.....do	101	56.0	5.6	+ 46.0	[2] − 5.8
486	Uncultivated	None.	6.0	(1)	....	....
486	.....do	14	18.0	7.5	+ 12.0	....
486	.....do	28	25.0	12.6	+ 19.0	[2] + 5.1
486	.....do	42	34.5	14.0	+ 28.5	[2] + 6.5
486	.....do	101	70.0	16.8	+ 64.0	[2] + 9.3

[1] Not determined. [2] Gain or loss after 14 days.

From the above table it will be seen that nitrification and ammonification were stimulated by the brief aeration and that a maximum nitrate and ammonia content was reached in about four weeks, except in the case of soils Nos. 485 and 486. It is of special interest that the intensity of both nitrification and ammonification in the uncultivated soils was considerably less in every instance except No. 486 than in the corresponding cultivated soil, which again points to the fact that tillage, for a short time only, is not sufficient to cause vigorous bacterial action. Soil 486 at first appears to be an exception, but it should be remembered that aerated conditions ensue in this soil without cultivation. The data obtained from it, therefore, the more strongly emphasizes the fact that aeration not only supplies the oxygen necessary to bacterial action, but also brings about other changes, directly or indirectly, which appear to be fundamental to vigorous bacterial action.

EFFECTS OF LIME, INFUSIONS, AND THE LIKE, ON AMMONIFICATION AND NITRIFICATION.

There is a popular belief in Hawaii that the sod lands are acid, due to anaerobic fermentation, and that the acidity can be overcome (neutralized) by bringing about aerated conditions for a sufficient length of time. Thus it is that the farmer explains the beneficial effects of tillage. On the other hand, bacteriologists hold that bacteriotoxins may accumulate in soils in certain conditions, and that the nitrifying organisms either may not be present in soils long remaining under anaerobic conditions, or lose in part their physiological activity. In order to throw some light on these questions infusions from a soil containing vigorous nitrifying and ammonifying floras were added to portions of the cultivated and uncultivated soils, and in addition, dried blood at the rate of 2 grams and calcium carbonate at the rate of 1 gram per 100 grams of soil. After bringing to optimum moisture with sterile water, the soils were kept in tumblers at temperatures from 27° to 30° C. for 7 days in the ammonification experiments, and 21 days in the nitrification experiments. At the end of these periods the ammonia and nitrate were determined, as shown in the table following.

Ammonification and nitrification in cultivated and uncultivated soils.

[Parts per million.]

Lab. No.	Previous condition.	Treatment.	Ammonia nitrogen found.	Nitrate nitrogen found.	Gain (+) or loss (−).	
					Ammonia nitrogen.	Nitrate nitrogen.
329	Cultivated	None	37.8	135.0	+ 4.2	+ 60 0
329	do	Infusion	40.6	143.0	+ 7.0	+ 68.0
329	do	2 gm. dried blood	1,519.0	131.0	+1,485.4	+ 56.0
329	do	2 gm. dried blood+1 gm. $CaCO_3$	1,503.0	129.0	+1,469.4	+ 54.0
329	do	2 gm. dried blood+1 gm. $CaCO_3$+ infusion.	1,532.0	132.0	+1,498.4	+ 57.0
330	Uncultivated	None	11.9	22.4	− 2.1	+ 21.1
330	do	Infusion	12.6	20.8	− 1.4	+ 19.5
330	do	2 gm. dried blood	925.0	9.9	+ 911.0	+ 8.6
330	do	2 gm. dried blood+1 gm. $CaCO_3$	1,219.0	9.5	+1,205 0	+ 8.2
330	do	2 gm. dried blood+1 gm. $CaCO_3$+ infusion.	1,144.0	11.0	+1,130.0	+ 9.7
416	Cultivated	None	10.5	78.0	− 1.4	+ 38.0
416	do	1 gm. $CaCO_3$	6.3	82.0	− 5.6	+ 42.0
416	do	2 gm. dried blood	1,486.0	186.0	+1,474.1	+146.0
416	do	2 gm. dried blood+1 gm. $CaCO_3$	1,472.0	178.0	+1,460.1	+138.0
417	Uncultivated	None	5.9	2.5	− 1.8	+ 2.1
417	do	1 gm. $CaCO_3$	5.6	4.2	− 2.1	+ 3.8
417	do	2 gm. dried blood	1,034.0	3.5	+1,026.3	+ 3.1
417	do	2 gm. dried blood+1 gm. $CaCO_3$	1,130.0	2.2	+1,122.3	+ 1.8

The above results show that previous cultivation produced remarkable effects on ammonification and nitrification, especially the latter. Thus it was found that the nitrates in cultivated soils Nos. 329 and 416 without treatment increased in 21 days from 75 and 40 parts to 135 and 78 parts per million, respectively, while the nitrate in the corresponding uncultivated soils Nos. 330 and 417 increased from 1.3 and 0.4 parts to only 22.4 and 2.5 parts, respectively. Expressing these results in another way, cultivated soil No. 329 gained 60 parts per million of nitrate nitrogen, while the corresponding uncultivated soil No. 330 gained only 21.1 parts, and cultivated soil No. 416 gained 38 parts per million, while the uncultivated soil No. 417 gained only 2.1 parts.

The addition of active infusions brought about only slight increase in nitrification, while the addition of dried blood caused a slight decrease in nitrates in soil No. 329, and a considerably larger decrease in soil No. 330. On the other hand, nitrification in soil No. 416 was greatly stimulated by the addition of dried blood, but no effects were noticed in the corresponding uncultivated soil No. 417. Only slight effects were produced by the addition of calcium carbonate, thus showing that acidity is not the cause of the low nitrification in these soils.

Turning to the effects produced on ammonification, we find that neither the addition of active infusions nor of lime produced any effects, but that the ammonification of dried blood was active in every case, although proceeding with more vigor in the cultivated soils.

73729°—15——3

As further showing that something more than the mere supplying of free oxygen and active infusions is necessary in order to bring about nitrification in these soils, the experiments reported in the following table were carried out with soils Nos. 487 and 488. Soil No. 487 came from a field which had been thoroughly cultivated for a period of months, but for three weeks immediately previous to sampling excessively wet weather had prevailed, during which time the soil had been saturated practically all the time. Soil No. 488 represents the corresponding uncultivated soil.

Ammonification and nitrification in soils after continuous rains.

[Parts per million.]

Lab. No.	Previous condition.	Treatment.	Nitrate nitrogen found.	Ammonia nitrogen found.	Gain (+) or loss (−). Nitrate nitrogen.	Ammonia nitrogen.
487	Cultivated	None	13.2	53.0	+2.4	0.0
487	do	2 gm. dried blood	7.7	281.0	−3.1	+228.0
487	do	2 gm. dried blood+2 gm. $CaCO_3$	13.5	239.0	+2.7	+186.0
487	do	2 gm. dried blood+2 gm. $CaCO_3$+ infusion.	11.5	235.0	+0.7	+182.0
488	Uncultivated	None	2.7	60.2	+1.1	0.0
488	do	2 gm. dried blood	2.6	303.1	+1.0	+242.9
488	do	2 gm. dried blood+2 gm. $CaCO_3$	7.2	227.5	+5.6	+167.3
488	do	2 gm. dried blood+2 gm. $CaCO_3$+ infusion.	5.5	226.1	+3.9	+165.9

Here we see that ammonification took place, although not so actively as in the soils previously discussed, and that neither lime nor active infusions brought about any increase over that which occurred without them. Practically no nitrification took place in any portion of the cultivated or uncultivated soil. Thus while the previous cultivation had affected the nitrate content to a slight extent, the beneficial effects produced were very soon destroyed in the saturated condition. These soils contain a very high clay content and a small amount of humus, and the clay is exceedingly deflocculated. Continued rains, therefore, cause packing and bring about anaerobic conditions.

In the following series 10 cubic centimeters of infusion, obtained by vigorously shaking for 10 minutes 100 grams of uncultivated soil No. 417 with 200 cubic centimeters sterile water, were added to 100 grams of the cultivated soil No. 416 both with and without dried blood and calcium carbonate. At the same time infusions from the cultivated soil were added to portions of the uncultivated soil. After the usual incubation periods, ammonia and nitrate were determined, with the results shown in the table following.

Ammonification and nitrification as affected by infusion from the cultivated and uncultivated soils.

[Parts per million.]

Lab. No.	Previous condition.	Treatment.	Ammonia nitrogen found.	Nitrate nitrogen found.	Gain (+) or loss (−).	
					Ammonia nitrogen	Nitrate nitrogen.
416	Cultivated	None	10.5	78	− 1.4	+ 38.0
416	do	Infusion from No. 417	8.4	79	− 3.5	+ 39.0
416	do	2 gm. dried blood+1 gm. $CaCO_3$	1,472.0	178	+1,460.1	+138.0
416	do	2 gm. dried blood+1 gm. $CaCO_3$+infusion from No. 417.	1,437.0	157	+1,425.1	+117.0
417	Uncultivated	None	5.9	2.5	− 1.8	+ 2.1
417	do	Infusion from No. 416	5.6	3.8	− 2.1	+ 3.4
417	do	2 gm. dried blood+1 gm. $CaCO_3$	1,130.0	2.2	+1,122.3	+ 1.8
417	do	2 gm. dried blood+1 gm. $CaCO_3$+infusion from No. 416.	1,102.0	10.1	+1,094.3	+ 9.7

Practically no effects were produced by adding infusions from the cultivated to the uncultivated soils, or vice versa, except where dried blood and lime were added also. In these instances the infusions from the uncultivated soil caused a decrease in both nitrification and ammonification, whereas adding infusions from the cultivated soil caused a stimulation in nitrification. The inhibiting agent in the uncultivated soil, therefore, seems to be capable of being transferred in a water solution, although the results are not entirely convincing.

In order to study the effects brought about by sterilization, 100-gram portions were heated in an autoclave for two hours at a pressure of two atmospheres. After cooling, dried blood, calcium carbonate, and infusions from the original soils were added, optimum moisture conditions brought about, and incubated for the usual periods. The ammonia and nitrate that accumulated are shown in the following table:

Ammonification and nitrification after sterilizing in autoclave.

[Parts per million.]

Lab. No.	Previous condition.	Treatment.	Ammonia nitrogen found.	Nitrate nitrogen found.
416	Cultivated	No inoculation	12.5	57.5
416	do	Infusion from No 416	18.0	51.0
416	do	Infusion from No. 416+2 gm. dried blood	35.0	51.0
416	do	Infusion from No. 416+2 gm. dried blood+1 gm. $CaCO_3$	37.1	55.5
416	do	Infusion from No. 417	17.2	52.0
416	do	Infusion from No. 417+2 gm. dried blood	31.5	51.0
416	do	Infusion from No. 417+2 gm. dried blood+1 gm. $CaCO_3$	32.1	51.0
417	Uncultivated	No inoculation	12.2	.6
417	do	Infusion from No. 416	19.0	.8
417	do	Infusion from No. 416+2 gm. dried blood	35.2	.8
417	do	Infusion from No. 416+2 gm. dried blood+1 gm. $CaCO_3$	37.4	1.2
417	do	Infusion from No. 417	18.9	.4
417	do	Infusion from No. 417+2 gm. dried blood	31.5	1.4
417	do	Infusion from No. 417+2 gm. dried blood+1 gm. $CaCO_3$	31.6	1.9

These data show that the ammonifying organisms occurring in the cultivated and uncultivated soils are equally active, and that ammon-

ification took place in the two soils at practically the same rates after sterilization. On the other hand, no nitrification took place in the previously cultivated soil, and only to a very slight extent in that uncultivated. Ammonification took place much less vigorously in these soils after having been sterilized than before, although it should be remembered that in the initial stages of the ammonification a much smaller number of organisms was present than originally occurred in the soil. It is probable, however, in view of the absence of nitrification, and the fact that toxic conditions are known to be brought about by steam heat, that conditions somewhat toxic to ammonification were developed. The point of greatest interest in these results is that by sterilization in the autoclave changes were brought about in the cultivated and uncultivated soils, so that ammonification proceeded subsequently at practically the same rates in each.

In order to study the effects of still higher heating, portions of cultivated and uncultivated soils Nos. 329 and 330 were heated in porcelain dishes over the free flame of a Bunsen burner for a period of 10 hours. After cooling, each was treated with dried blood, calcium carbonate, and an active infusion. At the end of the usual incubation periods the ammonia and nitrate were determined, with the following results:

Ammonification and nitrification after burning.

[Parts per million.]

Lab. No.	Previous condition.	Treatment.	Ammonia nitrogen.	Nitrate nitrogen.
329	Cultivated	Immediately after burning	274.0	26.0
329	.....do	Active infusion	254.0	30.0
329	.....do	2 gm. dried blood+1 gm. $CaCO_3$+active infusion	899.0	32.4
330	Uncultivated	Immediately after burning	183.0	18.8
330	.....do	Active infusion	206.0	13.0
330	.....do	2 gm. dried blood+1 gm. $CaCO_3$+active infusion	929.0	17.1

In the first place heat caused an initial splitting off of a large amount of ammonia and a partial decomposition of the nitrate.[1] The subsequent ammonification was practically the same in each soil, however, while nitrification took place to a slight extent in soil No. 329 only. Thus, again, it is shown that heat reacts on the cultivated and uncultivated soils of Hawaii in such way as to bring them into similar conditions so far as bacterial action is concerned.

EFFECTS OF PARTIAL STERILIZATION.

For a number of years it has been known that plant stimulation may be brought about in soils by means of heating and by the application of such substances as carbon bisulphid, chloroform, etc. The

[1] Hawaii Sta. Bul. 30 (1913).

effects produced thereby are now commonly considered to be due to effects produced on the soil organisms either directly or indirectly. It has been known for some time, for instance, that, while the numbers of bacteria are generally reduced by partial sterilization, later on the bacterial population rises to abnormal proportions.

The different views held on this subject may be briefly summarized under three heads. First, the stimulation theory, by which it is held that the organisms which survive receive a direct stimulation from the treatment in addition to being supplied with an increase in food, made available by the sterilization, through decomposition of the soil organic matter, and in the cells of the organisms killed by the treatment. Second, the protozoan theory, according to which partial sterilization causes a destruction of certain phagocytes, which are supposed to feed upon the bacteria of soils and thus keep their numbers, and consequently their efficiency, in check. The amœbæ, infusoria, etc., being killed by the treatment, the remaining bacteria then multiply to great numbers, and the greater numbers of bacteria thus arising, rather than increased efficiency, cause the production of greater amounts of available nitrogen. Third, the bacteriotoxin and soil-film theory, according to which soils may contain substances poisonous to bacteria, which substances are capable of being decomposed at the temperatures employed in partial sterilization by means of heat. Volatile antiseptics, on the other hand, bring about bacterial stimulation through the solvent effects exerted on certain organic substances which surround the soil particles and which partially waterproof them, thus protecting the organic substances from the attack of bacteria. Upon evaporating the antiseptic, the dissolved substances become redistributed in such way as to leave the soil particles more open to bacterial invasion.

It will be noted that all but one of the theories above named presuppose the existence of a limiting agent in soils, the presence of one or more factors which operate to hold in check bacterial action. From the experiments above recorded it seems that the uncultivated soils of Hawaii contain some agent which limits bacterial action. It was shown, for instance, that the low bacterial efficiency is not due to the absence of oxygen as such, nor the specific organism, but rather to the presence of some factor which is susceptible of alteration by aeration, but considerable time is required for the aeration to exert its effects. It was suggested, therefore, that the toxic condition might be susceptible of alteration by partial sterilization. For this reason the following experiments were undertaken.

In these experiments the methods employed by Russell and Hutchinson [1] were used. The soils on reaching the laboratory were

[1] Jour. Agr. Sci., 3 (1909), pp. 111-144; also Russell and Golding, ibid., 5 (1912), pp. 27-47; Russell and Petherbridge, 5 (1912), pp. 86-111; Russell and Hutchinson, ibid., 5 (1913), pp. 152-221.

spread out on large sheets of paper and after becoming air dry, different portions were treated as follows: One portion of each soil containing from 600 to 800 grams, was heated in a water oven at 98° C. for two hours, then immediately placed in screw-cap glass jars. Other portions of equal weight were thoroughly mixed with toluol and carbon bisulphid at the rate of 4 cubic centimeters per 100 grams of soil, then placed in tight-fitting screw-cap jars, in which condition the sample stood for three days. These portions were then spread out in thin layers on clean paper, and the antiseptic allowed to evaporate for three additional days, when no odor of the antiseptic could be detected. The treated samples and also an untreated portion of each soil were then brought to optimum moisture by adding sterile water, placed in large fruit jars, loosely stoppered, and kept in a dark closet at about 28° C. The moisture was maintained by the addition of sterile water from time to time. At different intervals portions were withdrawn with a sterile spatula, and the nitrate and ammonia determined. The results are shown in the following table:

Ammonia and nitrate nitrogen in partially sterilized soils.

[Parts per million of the air-dried soil.]

AMMONIA NITROGEN.

Treatment.	Cultivated soil No. 329.					Uncultivated soil No. 330.				
	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.
Untreated	33.6	39.2	22.4	28.0	33.6	14.0	19.6	11.2	22.4	28.0
Heated to 98° C.	33.6	104.8	106.4	128.8	123.2	14.0	67.2	72.8	84.0	78.4
Toluol	33.6	117.6	114.8	126.0	131.6	14.0	89.6	114.8	120.4	126.0

NITRATE NITROGEN.

Treatment.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.
Untreated	75.0	220.0	220.0	168.0	220.0	1.3	13.0	14.6	18.8	7.0
Heated to 98° C.	75.0	150.0	148.0	140.0	164.0	1.3	5.0	6.0	5.0	2.0
Toluol	75.0	190.0	180.0	160.0	65.0	1.3	38.0	34.8	33.2	27.0

TOTAL NITRATE AND AMMONIA NITROGEN.

Treatment.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.
Untreated	108.6	259.2	242.4	196.0	253.6	15.3	32.6	25.8	41.2	35.0
Heated to 98° C.	108.6	254.8	254.4	268.8	287.2	15.3	72.2	78.8	89.0	80.4
Toluol	108.6	307.6	294.8	286.0	196.6	15.3	127.6	149.6	153.6	153.0

GAINS IN NITRATE AND AMMONIA NITROGEN.

Treatment.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.
Untreated	....	150.6	133.8	87.4	145.0	....	17.3	10.5	25.9	19.7
Heated to 98° C.	....	146.2	145.8	160.2	178.6	....	56.9	63.5	73.7	65.1
Toluol	....	199.0	186.2	177.4	88.0	....	112.3	134.3	138.3	137.7

Ammonia and nitrate nitrogen in partially sterilized soils—Continued.

AMMONIA NITROGEN.

Treatment.	Cultivated soil No. 416.					Uncultivated soil No. 417.				
	At the beginning.	After 7 days.	After 14 days.	After 21 days.	After 28 days.	At the beginning.	After 7 days.	After 14 days.	After 21 days.	After 28 days.
Untreated	19.6	11.2	14.0	16.8	28.0	22.4	53.2	42.0	48.8	42.0
Heated to 98° C	33.6	86.8	100.8	106.4	109.2	32.8	112.0	148.4	159.6	168.0
Toluol	22.4	78.4	100.8	109.2	120.4	25.2	120.4	154.0	162.4	179.2

NITRATE NITROGEN.

Untreated	70.0	90.0	92.0	86.0	90.0	0.6	0.6	13.0	8.8	12.0
Heated to 98° C	68.0	65.0	70.0	64.0	60.0	.7	2.3	8.8	.7	.6
Toluol	60.0	62.0	64.0	60.0	60.0	.4	.5	12.0	.7	.6

TOTAL NITRATE AND AMMONIA NITROGEN.

Untreated	89.6	101.2	106.0	102.8	118.0	23.0	53.8	55.0	57.6	54.0
Heated to 98° C	101.6	151.8	170.8	170.4	169.2	33.5	114.3	157.2	160.3	168.6
Toluol	82.4	140.4	164.8	169.2	180.4	25.6	120.9	166.0	163.1	179.8

GAINS IN NITRATE AND AMMONIA NITROGEN.

Untreated	....	11.6	16.4	13.2	28.4	....	30.8	32.0	34.6	31.0
Heated to 98° C	....	50.2	69.2	68.8	67.6	....	80.8	123.7	126.8	135.1
Toluol	....	58.0	82.4	86.8	98.0	....	95.3	140.4	137.5	154.2

The above data show that notable effects were produced by partial sterilization. For instance, as a result of the treatment, the ammonia content increased in both cultivated and uncultivated soils during the entire 28-day period of observation. Nitrification, on the other hand, was totally inhibited in soils Nos. 416 and 417, while in Nos. 329 and 330 it was considerably checked in most instances. The data showing the gains in total ammonia and nitrate bring out the effects more correctly since the nitrate formed must have passed through the ammonia stage. Cultivated soil No. 329 gained 33.6 parts per million as a result of heating, while the uncultivated soil No. 330 gained 45.4 parts. Treatment with toluol affected ammonification in soil No. 329 very much the same as heating, while in No. 330 toluol produced notably greater effects, but in the former instances denitrification became excessive, the nitrate content having decreased, after the eighth day, from 190 parts to 65 parts per million. Some denitrification took place in soil No. 330, although to a much less extent.

Considering soils Nos. 416 and 417, we find that partial sterilization produced similar effects in both the cultivated and uncultivated soils, causing, on the one hand, a marked stimulation in the ammonification and, on the other, totally preventing nitrification. It is also noteworthy that at the end of 28 days the total nitrate and ammonia

nitrogen in the treated portions of the cultivated and uncultivated soils was practically the same. Ammonification was therefore the more markedly stimulated in the uncultivated soil, since the available nitrogen originally present was considerably less than in the cultivated soil.

In order to determine whether effects similar to those observed above would be produced in other island soils, the same treatments were applied to a soil from the experiment station grounds, No. 288, and to a rice soil, No. 292, which was previously devoted to rice experiments by this station. The results follow:

Effects of partial sterilization.

[Parts per million.]

Treatment.	Soil No. 288.					Soil No. 292.					
	Before treatment.	After 8 days.	After 14 days.	After 21 days.	After 28 days.	Before treatment.	After 7 days.	After 14 days.	After 21 days.	After 28 days.	After 35 days.
AMMONIA NITROGEN.											
Untreated	16.8	28.0	11.2	16.4	14.0	2.0	19.6	14.0	11.2	11.2	14.0
Heated to 98° C.	16.8	44.8	39.2	39.2	22.4	2.0	33.6	39.2	36.4	42.0	47.6
Toluol	16.8	36.4	11.2	14.0	19.6	2.0	30.8	30.8	16.8	11.2	16.8
NITRATE NITROGEN.											
Untreated	4.7	36.0	44.0	40.0	40.0	0.5	24.0	27.5	33.4	37.6	47.0
Heated to 98° C.	4.7	28.0	37.2	42.0	67.0	.5	6.5	14.5	16.0	24.8	26.5
Toluol	4.7	32.0	68.0	[1] 39.0	70.0	.5	1.4	14.5	25.0	38.0	47.0
TOTAL AMMONIA AND NITRATE NITROGEN.											
Untreated	21.5	64.0	55.2	56.4	54.0	2.5	43.6	41.5	44.6	48.8	61.0
Heated to 98° C.	21.5	72.8	76.4	81.2	89.4	2.5	40.1	53.7	52.4	66.8	74.1
Toluol	21.5	68.4	79.2	53.0	89.6	2.5	32.2	45.3	41.8	49.2	63.8
GAINS IN AMMONIA AND NITRATE NITROGEN.											
Untreated	......	42.5	33.7	34.9	32.5	41.1	......	39.0	42.1	46.3	58.5
Heated to 98° C.	......	51.3	54.9	59.7	67.9	37.6	......	51.2	49.9	64.3	71.6
Toluol	......	46.9	57.7	31.5	68.1	29.7	......	42.8	39.3	46.7	61.3

[1] Too low, probably due to error of determination.

Thus it is shown that ammonification was greatly stimulated in soil No. 288 by heating to 98° C. and by the addition of toluol. But the ammonia was prevented from accumulating toward the close of the experimental period by the activity of nitrification, whereas nitrification was partially inhibited in soil No. 292. The total ammonia and nitrate present at the different intervals show that an increase in the amounts of available nitrogen was produced by partial sterilization, but the effectiveness of the treatment was much greater in the soil from the experiment station grounds than in the rice soil. In fact, the total ammonia and nitrate at the different intervals in the portions of soil No. 292 treated with toluol were practically the

same as those in the untreated portions, while the increases in the heated portions were small. The effects produced with soil No. 288, on the other hand, were notable, amounting to more than 100 per cent increases in the available nitrogen.

The conclusion to be drawn from the above experiments is that ammonification in Hawaiian soils may be greatly stimulated by partial sterilization, and that, in a few instances, stimulation may result in nitrification, although it is temporarily inhibited.

It is claimed by Russell and Hutchinson[1] that the stimulation given to ammonification by partial sterilization may be slowly overcome by reinoculation with a small portion of the original soil. They found, for example, that the numbers of bacteria in the reinoculated portions decreased, gradually diminishing in numbers until approximately the same numbers were found as in the untreated soil, and that the ammonia content also decreased, the amounts found being roughly proportional to the number of bacteria present. They attribute these phenomena to the reintroduction into the treated soil of the limiting agent (believed by them to be protozoa) that occurs in natural soils, which agent, they hold, is destroyed by partial sterilization. For the purpose of studying the effects thus produced in Hawaiian soils, the same treatments as were employed in the previous experiments were applied to different soils, and they were reinoculated by adding 5 per cent by weight of the original soil. Observations over a much longer period than was employed in the previous experiments were made and optimum moisture conditions maintained throughout. The results are recorded in the following tables:

Effects of partial sterilization, soil No. 428.

[Parts per million.]

AMMONIA NITROGEN.

Treatment.	At the beginning.	After 7 days.	After 14 days.	After 21 days.	After 35 days.	After 63 days.	After 138 days.	After 201 days.
Untreated	106.4	123.2	123.2	95.2	75.6	5.6	5.6	14.0
Heated to 98° C	103.6	128.8	141.7	159.6	171.6	207.2	159.6	11.2
Heated + 5 per cent original soil	103.4	137.2	145.6	154.0	162.4	16.8	2.8	16.4
Toluol 4 per cent	100.8	151.2	154.0	170.8	182.0	210.0	120.4	22.4
Toluol + 5 per cent original soil	100.8	154.0	148.4	170.8	171.6	14.0	5.6	14.0
CS_2 4 per cent	98.0	126.0	142.8	156.4	164.0	210.0	240.8	268.8
CS_2 + 5 per cent original soil	98.0	137.2	145.6	168.0	164.0	204.4	168.0	11.2

NITRATE NITROGEN.

Treatment.	At the beginning.	After 7 days.	After 14 days.	After 21 days.	After 35 days.	After 63 days.	After 138 days.	After 201 days.
Untreated	55.5	74.0	68.0	88.0	94.0	225.0	310.0	330.0
Heated to 98° C	53.5	64.0	67.5	58.0	56.0	77.5	160.0	280.0
Heated + 5 per cent original soil	53.5	64.0	62.0	56.0	60.0	235.0	380.0	340.0
Toluol 4 per cent	54.5	64.0	62.0	56.0	60.0	75.0	180.0	260.0
Toluol + 5 per cent original soil	54.5	64.0	62.0	60.0	60.0	232.5	290.0	330.0
CS_2 4 per cent	55.0	56.0	64.0	64.0	56.0	72.0	80.0	75.0
CS_2 + 5 per cent original soil	55.0	60.0	62.0	64.0	62.0	67.5	185.0	290.0

[1] Loc. cit.

Effects of partial sterilization, soil No. 428—Continued.

TOTAL NITRATE AND AMMONIA NITROGEN.

Treatment.	At the beginning.	After 7 days.	After 14 days.	After 21 days.	After 35 days.	After 63 days.	After 138 days.	After 201 days.
Untreated	161.9	197.2	191.2	183.2	169.6	230.6	315.6	344.0
Heated to 98° C	157.1	192.8	209.2	217.6	227.6	284.8	319.6	291.2
Heated + 5 per cent original soil	156.9	201.2	207.6	210.0	222.4	251.8	382.8	356.4
Toluol 4 per cent	155.3	215.2	216.0	226.8	242.0	285.0	300.4	282.4
Toluol + 5 per cent original soil	155.3	218.0	210.4	230.8	231.6	246.5	295.6	344.0
CS_2 4 per cent	153.0	182.0	206.8	220.4	220.0	282.0	320.8	343.8
CS_2 + 5 per cent original soil	153.0	197.2	207.6	232.0	226.0	271.9	353.0	301.2

GAINS IN NITRATE AND AMMONIA NITROGEN.

Untreated	....	35.3	29.3	21.3	7.7	68.7	153.7	182.1
Heated to 98° C	....	35.7	52.1	60.5	70.5	127.7	162.5	134.1
Heated + 5 per cent original soil	....	44.3	50.7	53.1	65.5	94.9	225.9	199.5
Toluol 4 per cent	....	59.9	60.7	71.5	86.7	129.7	145.1	127.1
Toluol + 5 per cent original soil	....	62.7	55.1	75.5	76.3	91.2	140.3	188.7
CS_2 4 per cent	....	29.0	53.8	67.4	67.0	129.0	167.8	190.8
CS_2 + 5 per cent original soil	....	44.2	54.6	79.0	73.0	118.9	200.0	148.2

Effects of partial sterilization, soil No. 485.

[Parts per million.]

AMMONIA NITROGEN.

Treatment.	Before treatment.	After 7 days.	After 14 days.	After 21 days.	After 28 days.	After 35 days.	After 94 days.	After 156 days.
Untreated	7.0	8.4	16.8	14.0	22.4	8.4	8.4	14.0
Heated to 98° C	7.0	36.4	56.0	46.7	22.4	16.8	5.6	11.2
Heated + 5 per cent original soil	7.0	39.2	44.8	39.2	8.4	11.2	2.8	14.0
Toluol 4 per cent	7.0	47.6	61.6	61.6	33.6	11.2	8.4	11.2
Toluol + 5 per cent original soil	7.0	42.0	56.0	33.6	14.0	11.2	8.4	14.0
CS_2 4 per cent	7.0	44.8	64.4	67.2	70.0	70.0	86.8	75.6
CS_2 + 5 per cent original soil	7.0	42.0	61.6	67.2	70.0	72.8	11.2	11.2

NITRATE NITROGEN.

Untreated	10.0	18.0	23.5	30.0	30.0	32.0	62.5	87.5
Heated to 98° C	10.0	13.0	15.0	30.0	66.0	82.5	92.5	120.0
Heated + 5 per cent original soil	10.0	14.8	20.0	32.5	70.0	75.0	92.5	117.5
Toluol 4 per cent	10.0	10.0	8.4	16.0	36.0	65.0	80.0	100.0
Toluol + 5 per cent original soil	10.0	12.0	14.8	27.5	62.0	72.5	97.5	105.0
CS_2 4 per cent	10.0	1.0	2.8	5.7	7.6	8.0	10.6	31.5
CS_2 + 5 per cent original soil	10.0	2.5	5.0	8.5	8.6	9.8	97.5	83.5

TOTAL NITRATE AND AMMONIA NITROGEN.

Untreated	17.0	26.4	40.3	44.0	52.4	40.4	70.9	101.5
Heated to 98° C	17.0	49.4	71.0	76.7	88.4	99.3	98.1	131.2
Heated + 5 per cent original soil	17.0	54.0	64.8	71.7	78.4	86.2	95.3	131.5
Toluol 4 per cent	17.0	57.6	70.0	77.6	69.6	76.2	88.4	111.2
Toluol + 5 per cent original soil	17.0	54.0	70.8	61.1	76.0	83.7	105.9	119.0
CS_2 4 per cent	17.0	45.8	67.2	72.9	77.6	78.0	97.4	107.1
CS_2 + 5 per cent original soil	17.0	44.5	66.6	75.7	78.6	82.6	108.7	94.7

GAINS IN NITRATE AND AMMONIA NITROGEN.

Untreated	....	9.4	23.3	27.0	35.4	23.4	53.9	84.5
Heated to 98° C	....	32.4	54.0	59.7	71.4	82.3	81.1	114.2
Heated + 5 per cent original soil	....	37.0	47.8	54.7	61.4	69.2	78.3	114.5
Toluol 4 per cent	....	40.6	53.0	60.6	52.6	59.2	71.4	94.2
Toluol + 5 per cent original soil	....	37.0	53.8	44.1	59.0	66.7	88.9	102.0
CS_2 4 per cent	....	28.8	50.2	55.9	60.6	61.0	80.4	90.1
CS_2 + 5 per cent original soil	....	27.5	49.6	58.7	61.6	65.6	91.7	77.7

Effects of partial sterilization, soil No. 486.

[Parts per million.]

Treatment.	Before treatment.	After 7 days.	After 14 days.	After 21 days.	After 28 days.	After 35 days.	After 94 days.	After 156 days.
AMMONIA NITROGEN.								
Untreated	8.0	8.4	14.0	14.0	11.2	14.0	16.8	11.2
Heated to 98° C	8.0	72.8	100.8	84.0	39.2	16.8	8.4	14.0
Heated + 5 per cent original soil	8.0	70.0	81.2	72.8	16.8	16.8	16.8	14.0
Toluol 4 per cent	8.0	78.4	98.0	103.6	106.4	117.6	8.4	11.2
Toluol + 5 per cent original soil	8.0	70.0	89.6	100.8	50.4	16.8	11.2	14.0
CS_2 4 per cent	8.0	64.6	89.6	95.2	95.2	100.8	114.8	112.0
CS_2 + 5 per cent original soil	8.0	72.8	100.8	95.2	106.2	109.2	11.2	11.2
NITRATE NITROGEN.								
Untreated	6.0	18.0	20.0	25.0	25.0	34.0	70.0	87.5
Heated to 98° C	6.0	14.0	10.0	19.0	55.0	102.5	107.5	170.0
Heated + 5 per cent original soil	6.0	8.0	14.0	26.0	64.0	90.0	117.5	140.0
Toluol 4 per cent	6.0	5.0	5.8	5.5	5.5	7.5	90.0	140.0
Toluol + 5 per cent original soil	6.0	5.0	7.0	9.0	40.0	91.0	120.0	135.0
CS_2 4 per cent	6.0	0.5	2.0	2.5	3.0	3.0	7.6	22.0
CS_2 + 5 per cent original soil	6.0	0.5	2.0	3.0	3.0	2.8	102.5	130.0
TOTAL NITRATE AND AMMONIA NITROGEN.								
Untreated	14.0	26.4	34.0	39.0	36.2	48.0	86.8	98.7
Heated to 98° C	14.0	86.8	110.8	103.0	94.2	119.3	115.9	184.0
Heated + 5 per cent original soil	14.0	78.0	95.2	98.9	80.8	106.8	134.3	154.0
Toluol 4 per cent	14.0	83.4	103.8	109.1	111.9	125.1	98.4	151.2
Toluol + 5 per cent original soil	14.0	75.0	96.6	109.8	90.4	107.8	131.2	149.0
CS_2 4 per cent	14.0	65.1	91.6	97.7	98.2	103.8	122.4	134.0
CS_2 + 5 per cent original soil	14.0	73.3	102.8	98.2	109.4	112.0	113.7	141.2
GAINS IN NITRATE AND AMMONIA NITROGEN.								
Untreated	....	12.4	20.0	25.0	22.2	34.0	72.8	84.7
Heated to 98° C	....	72.8	96.8	89.0	80.2	105.3	101.9	170.0
Heated + 5 per cent original soil	....	64.0	81.2	84.9	66.8	92.8	120.3	140.0
Toluol 4 per cent	....	69.4	89.8	95.1	97.9	111.1	84.4	137.2
Toluol + 5 per cent original soil	....	61.0	82.6	95.8	76.4	93.8	117.2	135.0
CS_2 4 per cent	....	51.1	77.6	83.7	84.2	89.8	108.4	120.0
CS_2 + 5 per cent original soil	....	59.3	88.8	84.2	95.4	98.0	99.7	127.2

It will be seen that in each soil an increase in the ammonia content was effected by partial sterilization, but that after the lapse of a certain interval of time, varying in the different soils studied, and also in the same soil when partially sterilized by different means, nitrification set in, with the result that the ammonia content became reduced to a low and practically equal concentration in all the different portions of each soil, with the exception of those treated with carbon bisulphid. In this case the ammonia content increased throughout the time of observation, only slight nitrification having taken place, and then only after a lapse of several months. The addition of 5 per cent of the original soil to the partially sterilized portions produced more vigorous nitrification in the early periods, due no doubt to the introduction of active nitrifying organisms. The method of effecting partial sterilization probably killed the greater numbers of the nitrifying organisms present, as has been shown to take place by Russell and Hutchinson and others.

The total ammonia and nitrate present is of especial interest. It is noteworthy that in soil No. 428 partial sterilization produced a considerable increase in the available nitrogen at the different intervals up to 63 days from the time of treatment. After this time the available nitrogen continued to accumulate up to the 138th day, but at rates correspondingly less in the treated than in the untreated portions. Consequently the gains in available nitrogen during this period were less than during earlier periods. From the 138th to the 201st day, most of the partially sterilized portions lost available nitrogen, whereas the accumulation continued in the untreated portions; consequently at the end of the experimental period the untreated portions contained more nitrate and ammonia than a number of treated portions.

It will also be noted that reinoculation with 5 per cent of the original soil of the portions heated and treated with toluol caused an increase in available nitrogen, but in the carbon bisulphid portions exactly opposite effects were produced, that is, reinoculation resulted in a notable decrease in the available nitrogen.

Turning to soils Nos. 485 and 486, it will be seen that the partial sterilization stimulated ammonification throughout the experiment. Reinoculating the portions of No. 485, heated and treated with toluol, and the portions of No. 486, treated with toluol and carbon bisulphid, on the whole produced no effects, while the reinoculation of No. 485, treated with carbon bisulphid, and the heated portion of No. 486 caused a considerable reduction in the total nitrate and ammonia. On the whole, then, the effects produced by reinoculating the partially sterilized soils are not in harmony with those found by Russell et al.

It has been shown by Gainey [1] that the use of small amounts of antiseptics results in immediate stimulation of the bacteria without a reduction in the numbers present, such as takes place where larger amounts are used. Gainey further found that the application of different volatile antiseptics produced notable stimulation in the growth of crops, but he failed to detect a corresponding effect on the numbers of bacteria present.[2]

In the experiments reported above, the antiseptic was allowed to evaporate from the soil until no further odor could be detected. The treatments were made on air-dried soils, but, upon bringing to optimum moisture content and allowing to stand a few days, a faint odor of the antiseptics was detected in most instances. Where carbon bisulphid was employed rather distinct odors of the substance were noticed till near the close of the period of observation. Since it has

[1] Missouri Bot. Gard., Ann. Rpt., 23 (1912), pp. 147-169.

[2] In Gainey's experiments the moisture content of the soil was brought to one-third or one-half saturation before the antiseptic was added, and since the substances used are miscible with water to a slight extent only, it is possible that the different organisms present did not come in contact with the antiseptics.

been shown that Hawaiian soils have a remarkably high absorptive capacity [1] it was suggested that the treated portions absorbed small amounts of the antiseptics, which exerted stimulative effects on the surviving bacteria. As shown in the preceding tables, where carbon bisulphid was employed, nitrification did not set in until after a much longer time than when other methods of effecting partial sterilization were used. This may have been due to the inhibiting action of the carbon bisulphid absorbed.

The soils employed in the following experiment were Nos. 288 and 329, the same as employed previously, each of which had been found to show marked effects from partial sterilization. The portions used in previous experiments were treated soon after becoming air dry. In the following experiments, however, the soils had remained in the laboratory in the air-dried state for several months previous to the time of treatment. In the following table are shown the results:

Effects of partial sterilization on thoroughly desiccated soils.

[Parts per million.]

AMMONIA NITROGEN.

Treatment.	Soil No. 288.				Soil No. 329.			
	At the beginning.	After 15 days.	After 33 days.	After 82 days.	At the beginning.	After 15 days.	After 33 days.	After 80 days.
Untreated	19.6	22.4	5.6	2.8	56.0	72.8	89.6	50.4
Heated to 98° C	19.6	25.2	44.8	5.6	61.6	72.8	103.6	128.8
Heated+5 per cent original soil	19.6	16.2	25.2	5.6	61.6	72.8	95.2	140.0
Toluol 0.2 per cent	16.2	33.6	44.8	5.6	61.6	50.4	84.0	131.6
Toluol 4 per cent	19.6	00.0	8.4	8.4	64.4	64.4	75.6	100.8
Toluol 4 per cent+5 per cent original soil	19.6	00.0	5.6	5.6	64.4	72.8	92.4	109.2
CS_2 0.2 per cent	19.6	36.4	58.8	89.6	70.0	103.6	84.0	126.0
CS_2 4 per cent	16.2	42.0	70.0	84.0	70.0	61.6	84.0	162.4
CS_2 4 per cent+5 per cent original soil	16.2	39.2	58.8	72.8	70.0	75.6	92.4	162.4

NITRATE NITROGEN.

Treatment.	At the beginning.	After 15 days.	After 33 days.	After 82 days.	At the beginning.	After 15 days.	After 33 days.	After 80 days.
Untreated	17.5	41.0	50.0	120.0	152.0	137.5	195.0	280.0
Heated to 98° C	16.0	51.0	52.5	115.0	164.0	137.5	185.0	250.0
Heated to 98° C.+5 per cent original soil	16.0	28.5	52.0	115.0	164.0	145.0	195.0	205.0
Toluol 0.2 per cent	18.0	21.0	36.0	110.0	160.0	124.0	180.0	220.0
Toluol 4 per cent	16.8	46.0	55.0	110.0	160.0	150.0	195.0	225.0
Toluol 4 per cent+5 per cent original soil	16.8	35.0	60.0	120.0	160.0	137.5	185.0	200.0
CS_2 0.2 per cent	10.0	12.5	20.0	48.0	130.0	145.0	185.0	180.0
CS_2 4 per cent	4.5	1.0	5.5	35.0	160.0	147.0	175.0	130.0
CS_2 4 per cent+5 per cent original soil	4.5	1.0	5.0	3.0	160.0	132.5	170.0	135.0

TOTAL NITRATE AND AMMONIA NITROGEN.

Treatment.	At the beginning.	After 15 days.	After 33 days.	After 82 days.	At the beginning.	After 15 days.	After 33 days.	After 80 days.
Untreated	37.1	63.4	55.6	122.8	208.0	210.3	284.6	330.4
Heated to 98° C	35.6	76.2	97.3	120.6	225.6	210.3	288.6	378.8
Heated to 98° C.+5 per cent original soil	35.6	44.7	77.2	120.6	225.6	217.8	290.2	345.0
Toluol 0.2 per cent	34.2	54.6	80.8	115.6	221.6	174.4	264.0	351.6
Toluol 4 per cent	36.4	46.0	63.4	118.4	224.4	214.4	270.6	325.8
Toluol 4 per cent+5 per cent original soil	36.4	35.0	65.6	125.6	224.4	210.3	277.4	309.2
CS_2 0.2 per cent	29.6	48.9	78.8	137.6	200.0	248.6	269.0	306.0
CS_2 4 per cent	20.7	43.0	75.5	119.0	230.0	208.6	259.0	292.4
CS_2 4 per cent+5 per cent original soil	20.7	40.2	63.8	75.8	230.0	208.1	262.4	297.4

[1] Hawaii Sta. Bul. 35.

Effects of partial sterilization on thoroughly desiccated soils—Continued.

GAIN (+) OR LOSS (−) IN NITRATE AND AMMONIA NITROGEN.

Treatment.	Soil No. 288.				Soil No. 329.			
	At the beginning.	After 15 days.	After 33 days.	After 82 days.	At the beginning.	After 15 days.	After 33 days.	After 80 days.
Untreated	....	+26.3	+18.5	+ 85.7	....	+ 2.3	+76.6	+122.4
Heated to 98° C	....	+40.6	+61.7	+ 85.0	....	−15.3	+63.0	+153.2
Heated to 98° C.+5 per cent original soil	....	+ 9.1	+41.6	+ 85.0	....	− 7.8	+64.6	+119.4
Toluol 0.2 per cent	....	+20.4	+46.6	+ 81.4	....	−47.2	+42.4	+130.0
Toluol 4 per cent	....	+ 9.6	+27.0	+ 82.0	....	−10.0	+46.2	+101.4
Toluol 4 per cent+5 per cent original soil	....	− 1.4	+29.2	+ 89.2	....	−14.1	+53.0	+ 84.8
CS_2 0.2 per cent	....	+19.3	+49.2	+108.0	....	+48.6	+69.0	+106.0
CS_2 4 per cent	....	+22.3	+54.8	+ 98.3	....	−21.4	+29.0	+ 62.4
CS_2 4 per cent+5 per cent original soil	....	+19.5	+43.1	+ 55.1	....	−21.9	+32.4	+ 67.4

The above data show that greater irregularity resulted from the treatments than in any of the previously recorded experiments. At the end of 15 days no important increase in available nitrogen was found, except in the heated portions of soil No. 288 and the portions of No. 329 treated with 0.2 per cent carbon bisulphid. On the other hand, a decrease was observed in a number of instances. At that time the portions of No. 288 treated with carbon bisulphid contained practically no nitrate. After 33 days each of the treated portions contained an increased amount of available nitrogen, whereas no stimulation was manifest in soil No. 329, and after 82 days no increase was found in any instance except the portion of No. 288 treated with 0.2 per cent carbon bisulphid and those of No. 329 heated and treated with toluol. Reinoculating the portions of No. 288 treated with toluol was without effect, whereas in No. 329 it caused a reduction of from 325.8 to 309.2 parts per million. The use of 0.2 per cent of both toluol and carbon bisulphid proved equally as effective as 4 per cent.

It is notable that irregular and sometimes negative effects were produced by partial sterilization when applied after the soils had been air dry for several months, while the same treatment applied to the fresh soils produced regular and stimulating effects.

Before taking up the general discussion of the foregoing results, it will be of interest to examine the data already submitted, with a view to determining how long the stimulation continued in the different soils studied. In the table following the data presented in the preceding tables are brought together for the purpose of showing the gains in available nitrogen during the different periods.

Gain (+) or loss (−) in ammonia and nitrate nitrogen during successive periods.

[Parts per million.]

Treatment.	Soil No. 329.						Soil No. 330.					
	Days 1–8.	Days 8–14.	Days 14–21.	Days 21–28.	Days 8–28.	Days 14–28.	Days 1–8.	Days 8–14.	Days 14–21.	Days 21–28.	Days 8–28.	Days 14–28.
Check	+150.6	−16.8	−46.4	+57.6	− 5.6	+11.2	+ 17.3	− 6.8	+15.4	− 6.2	+ 2.4	+ 9.2
Heated	+146.2	− .4	+14.4	+18.4	+ 32.4	+32.8	+ 56.9	+ 6.6	+10.2	− 8.6	+ 8.2	+ 1.6
Toluol	+199.0	−12.8	− 8.8	−89.4	−111.0	−98.2	+112.[illegible]	+22.0	+ 4.0	− .6	+25.4	+ 3.4

Treatment.	Soil No. 416.						Soil No. 417.					
	Days 1–7.	Days 7–14.	Days 14–21.	Days 21–28.	Days 7–28.	Days 14–28.	Days 1–7.	Days 7–14.	Days 14–21.	Days 21–28.	Days 7–28.	Days 14–28.
Check	+11.6	+ 4.8	− 3.2	+15.2	+16.8	+12.0	+ 30.8	+ 1.2	+ 2.6	− 3.6	+ 0.2	− 1.0
Heated	+50.2	+19.0	− .4	− 1.2	+17.4	− 1.6	+ 80.8	+42.9	+ 3.1	+ 8.3	+54.3	+11.4
Toluol	+58.0	+24.4	+ 4.4	+11.2	+40.0	+15.6	+ 95.3	+45.1	− 2.9	+16.7	+58.9	+13.8

Treatment.	Soil No. 428.								
	Days 1–7.	Days 7–14.	Days 14–21.	Days 21–35.	Days 35–63.	Days 63–138.	Days 138–201.	Days 7–201.	Days 14–201.
Check	+35.3	− 6.0	− 8.0	−13.6	+61.0	+ 85.0	+28.4	+146.8	+152.8
Heated	+35.7	+16.4	+ 8.4	+10.0	+57.2	+ 34.8	−28.4	+ 98.4	+ 82.0
Heated+5 per cent original soil	+44.3	+ 6.4	+ 2.4	+12.4	+29.4	+131.0	−26.4	+155.2	+148.8
Toluol	+59.9	+ .8	+10.8	+15.2	+43.0	+ 15.4	−18.0	+ 67.2	+ 66.4
Toluol+5 per cent original soil	+62.7	− 7.6	+20.4	+ .8	+14.9	+ 49.1	+48.4	+126.0	+133.6
CS_2	+29.0	+24.8	+13.6	− .4	+62.0	+ 38.8	+23.0	+161.8	+137.0
CS_2+5 per cent original soil	+44.2	+10.4	+24.4	− 6.0	+45.9	+ 81.1	−51.8	+104.0	+ 93.6

Treatment.	Soil No. 485.								
	Days 1–7.	Days 7–14.	Days 14–21.	Days 21–28.	Days 28–35.	Days 35–94.	Days 94–156.	Days 7–156.	Days 14–156.
Check	+ 9.4	+13.9	+3.7	+ 8.4	−12.0	+30.5	+30.6	+75.1	+61.2
Heated	+32.4	+21.6	+5.7	+11.7	+10.9	− 1.2	+33.1	+81.8	+60.2
Heated+5 per cent original soil	+37.0	+10.8	+6.9	+ 6.7	+ 7.8	+ 9.1	+36.2	+77.5	+66.7
Toluol	+40.6	+12.4	+7.6	− 8.0	+ 6.6	+12.2	+22.8	+53.6	+41.2
Toluol+5 per cent original soil	+37.0	+16.8	−9.7	+14.9	+ 7.7	+22.2	+13.1	+65.0	+48.2
CS_2	+28.8	+21.4	+5.7	+ 4.7	+ .4	+19.4	+ 9.7	+61.3	+39.9
CS_2+5 per cent original soil	+27.5	+22.1	+9.1	+ 2.9	+ 4.0	+26.1	−14.0	+50.2	+28.1

Treatment.	Soil No. 486.								
	Days 1–7.	Days 7–14.	Days 14–21.	Days 21–28.	Days 28–35.	Days 35–94.	Days 94–156.	Days 7–156.	Days 14–156.
Check	+12.4	+ 7.6	+ 5.0	+ 2.8	+11.8	+38.8	+11.9	+77.9	+70.3
Heated	+72.8	+24.0	− 7.8	− 8.8	+25.1	− 3.4	+68.1	+97.2	+73.2
Heated+5 per cent original soil	+64.0	+17.2	+ 3.7	−18.1	+26.0	+27.5	+19.7	+76.0	+58.8
Toluol	+69.4	+20.4	+ 5.3	+ 2.8	+13.2	−26.7	+52.8	+67.8	+47.4
Toluol+5 per cent original soil	+61.0	+21.6	+13.2	−19.4	+17.4	+23.4	+17.8	+74.0	+52.4
CS_2	+51.1	+26.5	+ 6.1	+ .5	+ 5.6	+18.6	+11.6	+68.9	+42.4
CS_2+5 per cent original soil	+59.3	+29.5	− 4.6	+11.2	+ 2.6	+ 1.7	+27.5	+67.9	+38.4

Gain (+) or loss (−) in ammonia and nitrate nitrogen during successive periods—Cont'd.

Treatment.	Soil No. 288.				Soil No. 329.[1]			
	Days 1–15.	Days 15–33.	Days 33–82.	Days 15–82.	Days 1–15.	Days 15–33.	Days 33–80.	Days 15–80.
Check	+26.3	− 7.8	+67.2	+59.4	+ 2.3	+74.3	+45.8	+120.1
Heated	+40.6	+21.1	+23.3	+44.4	−15.3	+78.3	+90.2	+168.5
Heated+5 per cent original soil	+ 9.1	+32.5	+43.4	+75.9	− 7.8	+72.4	+54.8	+127.2
Toluol 0.2 per cent	+20.4	+26.2	+34.8	+61.0	−47.2	+89.6	+87.6	+177.2
Toluol 4 per cent	+ 9.6	+17.4	+55.0	+72.4	−10.0	+56.2	+55.2	+111.4
Toluol 4 per cent+5 per cent original soil	− 1.4	+30.6	+60.0	+90.6	−14.1	+67.1	+31.8	+ 98.9
CS_2 0.2 per cent	+19.3	+29.9	+58.8	+88.7	+48.6	+20.4	+37.0	+ 57.4
CS_2 4 per cent	+22.3	+32.5	+43.5	+76.0	−21.4	+50.4	+33.4	+ 83.4
CS_2 4 per cent+5 per cent original soil	+19.5	+23.6	+12.0	+35.6	−21.9	+54.3	+35.0	+ 89.3

[1] Second series.

It is thus shown that while stimulation in ammonification took place in practically every instance, the effects were, with but few exceptions, of short duration, generally ceasing after about 15 days from the time of treatment. Later on, the time varying in the different soils studied, the accumulation of available nitrogen became much slower in the partially sterilized soils, with the result that after a time the effects of the treatment disappeared entirely.

DISCUSSION.

From the investigations above recorded it has been shown that nitrification does not take place in most Hawaiian soils unless tillage is employed, and that the effects produced by aeration may be soon destroyed by continued wet weather. The virgin soils will not support nitrification until they have undergone aeration for several months, while the cultivated soils sustain active nitrification. The lack of nitrification in the former is not due to the absence of nitrifying organisms or acidity. Neither will the mere bringing about of aerobic conditions suffice. It is necessary that oxidizing conditions be maintained for a considerable length of time before nitrification will take place. Hawaiian soils, therefore, require the operation of the weathering process in order to become suitable to the activity of nitrifying bacteria.

Some of the inert virgin soils appear to contain soluble substances which inhibit nitrification. Sterilization in the autoclave affected both cultivated and uncultivated soil in such way as to render them practically equal in regard to subsequent ammonification and brought about conditions toxic to nitrification in each instance; similar effects were produced by heating to still higher temperatures.

Partial sterilization greatly stimulated ammonification, which stimulation persisted usually for about two weeks only, followed then by a retardation in ammonification to a point below that which took place in the untreated soil.

Nitrification was prevented for a short time by partial sterilization, but later regained its activity, finally becoming more active than in the untreated soil. Partial sterilization, however, did not bring about conditions in the inert soils as favorable to nitrification after reinoculation as are produced by continued aeration, and the total available nitrogen found in the partially sterilized soils after a lapse of several months was in a number of instances less than that in the untreated soil.

The reinoculation of partially sterilized soils with 5 per cent of the original soil in some instances caused a temporary reduction in the amount of nitrate and ammonia present, but this effect was not always permanent. In fact, the total nitrate and ammonia, in the soils kept under observation for the greatest length of time, was in some instances increased by reinoculation. In other instances no effects were produced, while in still other instances a permanent reduction in the amounts of available nitrogen was brought about.

The evidence presented above seems to point to the probability that the weathering process, aeration, brings about effects similar in nature but differing in degree from those produced by partial sterilization. These effects are believed by the writer to be in part of the nature of oxidation, but more largely physical, being affected through the changes produced in the colloidal soil films.

The protozoan theory of Russell and Hutchinson appears to be of doubtful application to these soils. It may be stated that some of the soils studied, especially No. 428, contained numerous organisms, apparently infusoria and amœbæ, so numerous indeed as to be easily detected under the low-power microscope.[1] No attempt was made to identify these organisms; but they appeared to be as numerous in the soil treated with toluol and carbon bisulphid [2] some weeks after treatment as in the untreated soil. In the heated portions, however, these organisms were not found, but ammonification was stimulated by the toluol and carbon bisulphid to practically the same extent as by heat.

There is much reason for the belief that the effects produced by different methods of partial sterilization are complicated and can not be satisfactorily explained as being due to a simple cause. It has been repeatedly shown that heating to 98° C. causes more or less decomposition of the organic matter of soils. Such changes certainly affect subsequent bacterial action. Frequently heat has been shown to bring about conditions temporarily toxic to the nitri-

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[1] Peck has previously reported the presence of protozoa in Hawaiian soils. See Hawaiian Sugar Planters, Sta., Agr. and Chem. Bul. 34 (1910).

[2] Greig-Smith found that the addition of protozoa to cultures did not reduce the numbers of bacteria during 70 days. Likewise the addition of untreated to partially sterilized soil produced no effects. See Proc. Linn. Soc. N. S. Wales, 37 (1912), pp. 655–672.

fying bacteria. From an extensive investigation carried out in this laboratory it was shown that an increase in the solubility of the inorganic constituents takes place by allowing arable soils to dry out in the laboratory [1] and that a considerably greater increase in solubility was produced by heating to 100° C. These effects, it is believed, are due to alterations in the colloidal films which surround soil particles and which seem to form an especially important feature of Hawaiian soils.

Alterations in the physical nature of colloidal films may reasonably be believed to take place, as a result of drying out or heating, being brought about through dehydration, evaporation from the interior to the exterior of the film, with the consequent deposition at the surface of the film of substances held in solution, and changes in the physical nature of the colloids. Such effects may be conceived to be of considerable biological significance, for new points of attack would thus become exposed, fresh supplies of organic material previously more or less protected from bacterial invasion would be laid open, and an increased food supply brought within their easy reach. In addition bacteriotoxins, if present, would probably undergo some decomposition, and the organisms surviving the heat would find in the cells of the organisms killed an additional store of material perhaps easily susceptible to decomposition.

The action of volatile antiseptics may be explained on very similar grounds, the effects produced in this case being on soil films, but brought about through solvent effects, after the manner described by Greig-Smith.[2] That there are substances in soils soluble in toluol, carbon bisulphid, chloroform,[3] etc., can hardly be doubted and that such substances would tend to accumulate around soil particles in and on the films also seems very probable. The volatile antiseptics would dissolve some of this material, although the amounts employed be small and upon evaporation a redistribution of the dissolved substances would be expected. Thus new surfaces of organic matter previously protected in part against bacterial invasion would become exposed. It seems probable, moreover, that some direct stimulation would result to the surviving organisms.

Thus, according to this view, the effects produced by partial sterilization are explainable largely on the basis of its making available to the surviving organisms food and organic materials through alterations in the colloidal films. The effects produced by aeration are probably in considerable part of the same nature with the addi-

[1] Hawaii Sta. Bul. 30 (1913).

[2] Proc. Linn. Soc. N. S. Wales, 35 (1910), pp. 808–822B; 36 (1911), pp. 609–612, 679–699; 37 (1912), pp. 238–243, 655–672.

[3] Texas Sta. Bul. 155 (1913).

tion of granulation effects and oxidative [1] decompositions, the latter of which are probably of special importance to the nitrifying organisms.

In these investigations only one of the different methods employed in soil bacteriology, namely, that of measuring the products formed, has been employed. There is urgent necessity for further work on this subject before the fundamental principles can be positively established.

THE LIME-MAGNESIA RATIO.

As stated in the introduction, lime and magnesia occur in Hawaiian soils in widely variable amounts, both relatively and absolutely, but generally speaking the magnesia content exceeds that of lime. The lime-magnesia ratio therefore is abnormal. For a number of years an increasing interest has been taken in this ratio in its relations to plant growth. Widely different conclusions have been reached.

The subject received one of its first important contributions from the work of Loew and May [2] in 1901. As a result of their experiments they concluded that the ratio of lime to magnesia has an important bearing upon the growth of crops. During the following years Loew and his coworkers in Japan [3] conducted further experiments along this line both in culture solutions and soil cultures, which further confirmed the conclusion arrived at formerly. As a result, the lime-magnesia ratio in soils has come to be known as the Loew theory. In general Loew found that a number of plants were considerably affected by variations in this ratio and that different ratios are best suited to the growth of different species.

Other investigators,[4] working with both field and pot cultures, have arrived at altogether different conclusions, while Voelcker,[5] after several years of careful pot experimentation, confirmed the theory so far as the growth of wheat was concerned.

From water cultures conducted at the Porto Rico Station, Gile [6] found that the concentration is of the greatest importance in determining whether the ratio of lime to magnesia exerts an influence on growth. At a low concentration he found that a wide variation in this ratio, 10:1 to 1:10, exerted no influence, while at a much higher concentration the ratio is of considerable significance. He concluded, however, that the higher concentration is rarely found in

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[1] The presence of ferrous iron compounds suggests itself as being related to the inactive state of nitrification in the uncultivated soils. Hawaiian soils contain unusually large amounts of iron, a considerable portion of which exists as ferrous oxid, but the water soluble ferrous iron occurs in extremely small amounts. The difference between the cultivated and uncultivated soils in this respect is very slight. See Hawaii Sta. Bul. 30.

[2] U. S. Dept. Agr., Bur. Plant Indus. Bul. 1.

[3] Aso, Bul. Col. Agr., Tokyo Imp. Univ., 4 (1902), pp. 361–370; 5 (1903), pp. 495–499; 6 (1904), pp. 97–102; Loew and Aso, ibid., 7 (1907), pp. 395–409.

[4] Lemmermann et al., Landw. Jahrb., 40 (1911), pp. 173–254.

[5] Jour. Roy. Agr. Soc. England, 73 (1912), pp. 325–338.

[6] Porto Rico Sta. Bul. 12 (1913).

soil solutions and therefore variations in this ratio in natural soils would rarely be consequential to crops.

Concerning the correctness of this conclusion opinions may well differ, since the concentration of the real soil solution, the film moisture, is not and can hardly be known in the present state of knowledge. The principle under consideration must of necessity be worked out from culture solutions or sand cultures, since in such a complex as an ordinary soil the number of variables are entirely too numerous to permit the establishing of the principle with definiteness.

From what is known regarding the different phases of the osmotic phenomenon in their bearings on the absorption of chemical substances by plant roots, it can hardly be doubted that any considerable variation in the concentration of such elements as calcium and magnesium in nutrient solutions is likely to be attended by physiological effects, especially in certain plants.

On the other hand, the effects produced on concentration by the application of the comparatively small amounts of lime and magnesia usually employed in field experiments can only be surmised. The mere application of a given amount of soluble calcium or magnesium by no means insures a corresponding increase in the concentration of these elements in the soil solution. Therefore that widely different results have been obtained in studies with soils of different origin, composition, and properties is not surprising.

Concerning the biological phases of this question a few experiments have been conducted.

In 1904 Löhnis [1] found that the addition of magnesium carbonate to culture solutions caused a loss of ammonia from the solutions, from which he concluded that this substance is unsuited to use in nitrification studies. In 1907 Lipman and Brown [2] found that the addition of magnesium carbonate to Omelianski solutions caused a loss of ammonia during sterilization, and that upon subsequent inoculation with a soil infusion still greater losses occurred, amounting in 25 days to more than 50 per cent of the ammonia originally present. Small losses of ammonia were also sustained where calcium carbonate was used. In addition only slight nitrification took place in the solutions which contained magnesium carbonate, reaching a maximum by the sixth day followed by denitrification, whereas active nitrification took place throughout the 25-day period of observation where calcium carbonate was used. On the other hand, Owen [3] in 1908 concluded that magnesium carbonate is better suited to the stimulation of nitrification than calcium, potassium, or ammonium carbonates.

[1] Centbl. Bakt. [etc.], 2. Abt., 13 (1904), pp. 706–715.

[2] Jour. Amer. Chem. Soc., 29 (1907), pp. 1358–1362.

[3] Georgia Sta. Bul. 81 (1908).

In 1907 Ashby [1] found that in the presence of magnesium carbonate, Azotobacter from the Rothamsted experimental plats fixed more nitrogen in mannite solutions, both in pure and mixed cultures, than in the presence of calcium carbonate. A mixture of the two carbonates proved more effective than calcium carbonate alone. The author concluded "that magnesium carbonate not only neutralizes more effectually than calcium carbonate any trace of acidity due to foreign organisms in the early stages of culture, but also prevents butyric fermentation, but at first it inhibits the growth of Azotobacter itself." In further investigation [2] he found that magnesium carbonate caused a greater loss of ammonia from ammonium sulphate solution than calcium carbonate. This loss Ashby attributed to the interaction between ammonium sulphate and the carbonates, whereby ammonium carbonate is formed, which in turn tends to volatilize from the solutions. Magnesium carbonate being more soluble than calcium carbonate, would, therefore, give rise to greater amounts of ammonium carbonate, for which reason he accounts for the greater losses in the former instances.

C. B. Lipman [3] found that, in the presence of more than very low concentrations of magnesium chlorid, the ammonification of peptone by *Bacillus subtilis* was greatly hindered, and that the simultaneous addition of varying amounts of calcium chlorid did not overcome the toxic effects. He concluded, therefore, that magnesium chlorid is toxic to the action of *B. subtilis*, and that there is no antagonism between calcium and magnesium chlorids so far as the ammonification of peptone is concerned. It should be borne in mind, however, that in general it has been found that calcium is not necessary to the growth of bacteria, and therefore, from the conception underlying Loew's theory, there need not be any antagonism between calcium and magnesium. The point of greatest interest in Lipman's experiments in this connection, however, is the fact that the magnesium salt actually proved toxic at low concentration.

In 1908 Fraps [4] found from some investigations with soils in Texas that the addition of calcium carbonate caused a greater stimulation to the nitrification of cottonseed meal than magnesium carbonate, and that a mixture of the two produced intermediate effects.

J. G. Lipman, P. E. Brown, and I. L. Owen [5] observed in 1910 that the addition of 1 gram of calcium carbonate per 100 grams of a soil from New Jersey caused a stimulation in the ammonification of dried blood, but hindered the ammonification of cottonseed meal. On the other hand, magnesium carbonate was toxic to the ammoni-

[1] Jour. Agr. Sci., 2 (1907), pp. 35–51.
[2] Idem, pp. 52–67.
[3] Bot. Gaz., 48 (1909), pp. 105–125; 49 (1910), pp. 41–50.
[4] Texas Sta. Bul. 106 (1908).
[5] New Jersey Stas. Rpt. 1910, p. 114.

fication of dried blood, but stimulated the ammonification of cottonseed meal. In the same year, Kellerman and Robinson [1] found that the addition of magnesium carbonate to a magnesian soil in quantities greater than 0.25 per cent depressed the formation of nitrates, while calcium carbonate exerted a stimulating effect.

In investigations carried out in India in 1910 and 1911, C. M. Hutchinson [2] found that the addition of magnesium carbonate to full strength Omelianski solutions caused considerable loss of ammonia but only slight losses from dilute solutions. Furthermore, neither the neutralization of the magnesium carbonate with sulphuric acid nor the synchronous addition of calcium carbonate overcame the loss. In nitrification experiments Hutchinson found that the addition of magnesium carbonate to dilute solutions partially prevented nitrate formation for a few weeks, but at the end of 12 weeks the toxic effects had disappeared. With full-strength solutions, nitrification was greatly reduced by magnesium carbonate, and again the toxic effects were not overcome by neutralizing the magnesium carbonate. Calcium carbonate, on the other hand, did not interfere with nitrification.

In 1912 the writer [3] conducted a series of experiments on this subject, using two sandy soils from California. In the ammonification of dried blood 85 milligrams of ammonia nitrogen were formed with calcium carbonate and only 53.9 milligrams with magnesium carbonate, and no antagonism was found between the two carbonates. In nitrification studies using dried blood, calcium carbonate produced about 50 per cent stimulation, but magnesium carbonate totally inhibited nitrification. In addition to preventing nitrification, magnesium carbonate also caused slight denitrification, the original nitrate content having been reduced from 5 milligrams per 100 to 2 milligrams, where 2 grams of magnesium carbonate was added, and finally no antagonism was found between calcium and magnesium carbonates.

In view of the results previously found and the fact that, in the main, conditions differing greatly from those encountered in field studies have been employed, it becomes important to study the question further. It is of special importance to study the effects of different ratios of lime and magnesia on the various phases of bacterial action in soils, since it is now recognized that so much depends upon the biological phenomena of soils. The following investigation is offered as a contribution to the ammonification and nitrification phases of this question.

[1] Science, n. ser., 32 (1910), p. 159.
[2] Mem. Dept. Agr. India, Bact. Ser., 1 (1912), No. 1.
[3] Univ. Cal. Pubs. Agr. Sci., 1 (1912), pp. 39–49.

EFFECTS OF CALCIUM AND MAGNESIUM CARBONATES ON AMMONIFICATION.

In experiments on this subject 100-gram portions of air-dried soils, selected so as to represent the principal types found in Hawaii, were thoroughly mixed with 2 grams of the nitrogenous materials and carbonates, then placed in tumblers, brought to optimum moisture, and covered with watch glasses. Dried blood was used as a source of nitrogen. After incubation for seven days, at from 27° to 29° C., the ammonia was determined by distillation in the usual way.

The soils used varied greatly in physical and chemical composition. No. 288 is a heavy ferruginous clay soil, containing 1.10 per cent lime and 7.94 per cent magnesia. No. 330 is a heavy clay soil from the pineapple section of the Wahiawa district. This sample contained less than 0.2 per cent of both lime and magnesia. No. 335 is coral sand soil already described. The results are shown in the following table:

Effects of calcium and magnesium carbonates on the ammonification of dried blood.

[Milligrams of ammonia nitrogen per 100 grams soil.]

Soil portions.	Carbonate added.	Soil No. 288.		Soil No. 330.		Soil No. 335.	
		Duplicates.	Averages.	Duplicates.	Averages.	Duplicates.	Averages.
1	....	59.9	....	83.4	....	99.3	....
2	None..........	77.0	68.4	63.8	73.6	93.8	96.5
3	0.1 gm. $CaCO_3$..........	93.1	....	62.7	....	....	....
4	0.1 gm. $CaCO_3$..........	77.0	85.0	65.5	64.1	....	....
5	0.5 gm. $CaCO_3$..........	85.8	....	(1)	....	....	....
6	0.5 gm. $CaCO_3$..........	95.5	90.6	89.0	89.0	....	....
7	1.0 gm. $CaCO_3$..........	91.4	....	69.7	....	....	....
8	1.0 gm. $CaCO_3$..........	87.6	89.5	83.4	71.5	....	....
9	2.0 gm. $CaCO_3$..........	(1)	....	57.1	....	....	....
10	2.0 gm. $CaCO_3$..........	95.0	95.0	88.2	72.6	....	....
11	4.0 gm. $CaCO_3$..........	57.1	....	84.0	....	....	....
12	4.0 gm. $CaCO_3$..........	59.9	58.5	108.8	96.4	....	....
13	8.0 gm. $CaCO_3$..........	87.6	....	105.0	....	....	....
14	8.0 gm. $CaCO_3$..........	94.9	91.2	123.2	114.1	....	....
15	0.1 gm. $MgCO_3$..........	78.7	....	51.8	....	....	....
16	0.1 gm. $MgCO_3$..........	94.9	86.6	79.5	65.6	....	....
17	0.5 gm. $MgCO_3$..........	100.0	....	49.8	....	....	....
18	0.5 gm. $MgCO_3$..........	82.0	91.0	65.8	57.8	....	....
19	1.0 gm. $MgCO_3$..........	99.7	....	112.0	....	57.3	....
20	1.0 gm. $MgCO_3$..........	(1)	99.7	121.8	116.9	64.7	62.0
21	2.0 gm. $MgCO_3$..........	90.4	....	125.3	....	54.0	....
22	2.0 gm. $MgCO_3$..........	98.0	94.2	125.6	125.4	54.2	54.1
23	4.0 gm. $MgCO_3$..........	84.0	....	108.5	....	54.0	....
24	4.0 gm. $MgCO_3$..........	68.6	76.3	113.4	111.4	56.8	55.4
25	8.0 gm. $MgCO_3$..........	64.4	....	89.9	....	49.6	....
26	8.0 gm. $MgCO_3$..........	64.1	64.2	99.4	94.6	52.4	51.0

[1] Lost.

The above results show a wide difference in the effects produced in the different soils. In soil No. 288 the addition of calcium carbonate up to 2 per cent caused a gradational increase in ammonia formation, but with larger amounts slightly less ammonia was found. With soil No. 330, calcium carbonate in amounts less than 4 per cent produced only slight effects, while the larger amounts stimulated ammonification. These effects may be due to physical causes, since these soils are extremely heavy and the addition of the larger amounts

of calcium carbonate probably exerted an effect upon the texture so as to permit better aeration.

Magnesium carbonate [1] produced effects in soil No. 288 similar to those produced by calcium carbonate. But in soil No. 330, a reduction in the amounts of ammonia formed was caused by the smaller amounts of magnesium carbonates, while the larger amounts caused considerable stimulation. In soil No. 335, magnesium carbonate markedly decreased the amounts of ammonia that accumulated.

EFFECTS OF CALCIUM AND MAGNESIUM CARBONATES ON THE AMMONIFICATION OF DRIED BLOOD AND SOY BEAN CAKE MEAL.

Two different nitrogenous substances were employed, dried blood and soy bean cake meal, the latter of which represents the residue left after expressing the oil from the soy bean, and is produced in certain parts of the Orient in enormous quantities, where it is used both as a feed and a fertilizer. The dried blood used contained 13.29 per cent nitrogen, the soy bean cake meal 8.28 per cent. Of the soils employed, No. 9 is highly manganiferous and silty in character; No. 292 is a gravelly loam of unusually high magnesium content; No. 428 contains a large amount of organic matter and considerable amounts of calcium carbonate; No. 448 is a yellow clay soil, taken from the grounds of the Hilo Boarding School; No. 461 is clay loam taken from the rice lands of the Hanalei Valley. The other soils studied have already been discussed. After mixing with the organic nitrogenous materials and carbonates, bringing to optimum moisture, and incubation for seven days, the ammonia was determined as usual. The results are shown in the following table:

Effects of calcium and magnesium carbonates on the ammonification of dried blood and soy bean cake meal.

[Average amount in milligrams of ammonia nitrogen formed per 100 grams of soil.]

Soil portions.	Carbonate added.	Soil No. 9.		Soil No. 292.		Soil No. 428.		Soil No. 448.		Soil No. 461.		Soil No. 485.		Soil No. 487.	
		Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.	Dried blood.	Soy-bean cake.
1,2...	None...........	51.9	99.1	156.9	94.1	53.4	74.3	39.3	78.1	94.4	98.3	45.9	79.9	31.0	77.0
3,4...	1.0 gm. $CaCO_3$..	54.4	103.7	160.3	97.2	52.6	79.5	42.0	80.0	118.1	93.1	.....	.....	27.2	83.2
5,6...	2.0 gm. $CaCO_3$...	55.4	104.8	158.9	99.5	64.4	82.4	42.7	82.5	126.2	93.2	46.7	90.0	30.8	87.0
7,8...	4.0 gm. $CaCO_3$...	56.1	103.4	160.1	96.8	61.3	88.9	44.3	88.9	116.6	95.4	.....	.....	31.3	84.2
9,10..	1.0 gm. $MgCO_3$..	68.0	104.1	175.0	93.9	68.6	78.5	53.6	95.1	119.8	94.5	.....	.....	42.1	83.6
11,12.	2.0 gm. $MgCO_3$..	70.9	103.6	163.8	95.0	93.6	82.7	67.6	98.8	89.6	94.1	60.7	91.7	50.0	85.7
13,14.	4.0 gm. $MgCO_3$..	65.9	98.7	172.0	92.3	109.9	92.5	73.5	100.8	82.8	89.9	.....	.....	38.3	80.7
15,16.	2.0 gm. $CaCO_3$+ 2 gm. $MgCO_3$.	69.8	101.3	......	90.7	......	86.8	68.9	97.3	102.6	91.3	61.6	91.6	46.5	90.9
17,18.	4.0 gm. $CaCO_3$+ 2 gm. $MgCO_3$.	70.9	104.8	......	92.4	98.7	83.4	67.6	95.9	99.7	92.4	62.2	97.7	52.4	91.1

[1] Baker's analyzed magnesium carbonate, having the composition, $3MgCO_3.Mg(OH)_2 3 H_2O$, was used in these experiments. In all other instances reported in this bulletin Merck's reagent magnesium carbonate, $MgCO_3$, was used.

Considering first the calcium carbonate, it will be seen that only slight effects were produced on the ammonification of either dried blood or soy bean cake meal in soils Nos. 9, 292, 428, 448, and 487, and on the ammonification of soy-bean cake in No. 461 and that of dried blood in No. 485, while considerable stimulation resulted in the ammonification of dried blood in No. 461 and of soy-bean cake in No. 485. With the addition of magnesium carbonate, the ammonification of dried blood was stimulated in every soil except No. 461, as also was the ammonification of soy bean cake meal in Nos. 428, 448, and 485. On the other hand, magnesium carbonate produced no effects on the ammonification of soy-bean cake in soils Nos. 9, 292, and 461. In one case only—dried blood in soil No. 461—the addition of magnesium carbonate caused a decrease in the amounts of ammonia found.

In those instances where magnesium carbonates produced stimulation the further addition of calcium carbonate was without effect on this stimulation. In the one instance where magnesium carbonate proved toxic the addition of calcium carbonate, however, seems to have overcome the toxicity. It is doubtful, however, whether this is a true case of antagonism, so far as the biological processes are concerned.

The effects produced by magnesium carbonate in Hawaiian soils, therefore, proved to be quite opposite to those found in ammonification studies in solutions and in the few soils previously reported. The majority of soils used above contained an excess of magnesia over lime—No. 292 especially so—yet we find that the addition of calcium carbonate produced only slight stimulation, whereas the addition of magnesium carbonate usually caused considerable stimulation. It seems justifiable to conclude, therefore, that the lime-magnesia ratio as such has but little or no significance to the ammonification process. The above results, moreover, are in harmony with the observations of Lipman et al. in that the effects produced by magnesium carbonate depend in some instances on the nitrogenous material being acted upon; and, finally, it is of interest that magnesium carbonate caused a more marked stimulation of the ammonification of dried blood than of soy bean cake meal.

The inference has already been made that the smaller amounts of ammonia found where magnesium carbonate was added are due to the formation of ammonium carbonate and its volatilization rather than to an actual inhibition of the ammonification process. In order to throw some light on this point, further experiments were carried out with soil No. 335. In these experiments 100-gram portions were mixed with the carbonates and dried blood, then brought to optimum moisture by the addition of sterile water, and placed in wide-mouthed bottles fitted with two-hole rubber stoppers,

through which a slow current of air was slowly drawn by means of a filter pump. The air was first drawn through a solution of sulphuric acid in order to free it from all traces of ammonia, then after passing over the soil in the bottles was again drawn through sulphuric acid. After seven days' incubation the ammonia was determined, both in the soil and in the sulphuric acid. The results are shown in the following table:

Ammonification of dried blood, showing total ammonia formed.

Soil portions.	Carbonate added.	Soil 335.			
		Ammonia nitrogen found.	Ammonia nitrogen volatilized.	Totals.	Averages.
		Mg.	*Mg.*	*Mg.*	*Mg.*
1	2 gm. $CaCO_3$	56.7	17.4	74.1	
2	2 gm. $CaCO_3$	67.3	10.9	78.2	76.1
3	2 gm. $MgCO_3$	38.5	17.2	55.7	
4	2 gm. $MgCO_3$	40.5	22.4	62.9	59.3

The above data show that 14.1 milligrams of ammonia nitrogen was volatilized under the influence of calcium carbonate and 19.8 milligrams with magnesium carbonate. On the other hand, 62 milligrams accumulated in the soil where calcium carbonate was added and only 39.5 milligrams with magnesium carbonate. Combining the ammonia accumulated and that volatilized, we find that 76.1 milligrams of nitrogen was ammonified in the presence of calcium carbonate and only 59.3 milligrams in the presence of magnesium carbonate. It is thus shown that in this soil magnesium carbonate was actually toxic to ammonification. It will be recalled that the soil used is composed principally of grains of coral sand ($CaCO_3$), yet the addition of relatively small amounts of magnesium carbonate proved toxic. The conclusion, therefore, seems justifiable that magnesium carbonate is toxic to the ammonifying flora of this soil, although there are other factors that must be considered.

EFFECTS OF NATURAL LIMESTONES ON AMMONIFICATION.

Notwithstanding the theoretical interest attached to the effects produced by magnesium carbonate, it is of more practical value to determine the effects produced by the naturally occurring double carbonate of magnesium and calcium [$MgCa(CO_3)_2$], dolomite, which is present in greater or lesser amounts in practically all limestones which are now being applied to soils. Through the kindness of A. F. Whiting, of the University of Illinois, a few pounds of pulverized limestone ($CaCO_3$) and a very pure dolomite were obtained, each of which is reported as being used on a large scale.

In order to study the effects produced by these materials, both as regards stimulation and toxicity, three of the soils previously studied were employed, using also chemically pure carbonates, both singly and combined, in amounts corresponding to those in which the carbonates occur in dolomite. The results are shown in the following table:

Ammonification, showing effects produced by natural limestones.

[Average amount in milligrams of ammonia nitrogen per 100 grams soil.]

Soil portions.	Carbonate added.	Soil No. 335.		Soil No. 465.	Soil No. 516.
		Dried blood.	Soy-bean cake.	Dried blood.	Dried blood.
1, 2	None	50.2	55.7	102.2	92.7
3, 4	2 gm. $CaCO_3$	54.2	53.7	110.6	99.7
5, 6	2 gm. $MgCO_3$	30.2	46.4	114.1	116.1
7, 8	1.1 gm. $CaCO_3$+0.9 gm. $MgCO_3$	29.9	46.9	121.6	109.8
9, 10	2 gm. limestone ($CaCO_3$)	50.5	56.7	108.9	94.5
11, 12	2 gm. dolomite	49.3	55.4	104.6	92.2

Again, it is shown that calcium carbonate produced only slight stimulation in the ammonification of dried blood and was without effect on that of soy bean cake meal. Magnesium carbonate, on the other hand, was toxic to the ammonification of dried blood in soil No. 335 but stimulating in the other soils. The effects produced by addition of the two carbonates were similar to those produced by magnesium carbonate alone. Where the natural limestones were added, on the other hand, it will be seen that both the calcareous and the dolomitic limestones produced effects very similar to those produced by calcium carbonate. Dolomite neither proved toxic in soil No. 335 nor stimulating in soils Nos. 465 and 516. Thus it is shown that the effects produced by dolomite in no way simulated those produced by magnesium carbonate. Further discussion on this point will be made after the results from the nitrification studies have been presented.

EFFECTS OF CALCIUM AND MAGNESIUM CARBONATES ON NITRIFICATION.

In the nitrification experiments, 100-gram portions of air-dried soils, after thoroughly mixing with the nitrogenous materials and carbonates, were kept at optimum moisture in tumblers for 21 days, after which the nitrates were determined by the phenol-disulphonic acid method. Dried blood and soy bean cake meal were added at the rate of 2 grams per 100 grams of soil, and ammonium sulphate at the rate of 1.2 grams, which furnished nitrogen in an amount intermediate between those supplied by the dried blood and soy bean cake meal.

Effects of calcium and magnesium carbonates on nitrification.

[Milligrams of nitrate nitrogen per 100 grams soil.]

Soil portions.	Carbonate added.	Soil No. 292.		Soil No. 288.		Soil No. 329.		Soil No. 428.		Soil No. 448.		Soil No. 485.	
		Duplicates.	Averages.	Duplicates.	Averages.	Duplicates.	Averages.	Duplicates.	Averages.	Duplicates.	Averages.	Duplicates.	Averages.
	DRIED BLOOD, 2 GRAMS.												
1	None	9.3	......	12.3	......	20.0	......	3.2	......	6.5	......	5.0	......
2	......do	10.0	9.6	12.5	12.4	20.0	20.0	3.2	3.2	6.0	6.2	4.7	4.8
3	2 gm. $CaCO_3$	11.3	......	12.5	......	19.5	......	3.7	......	11.0	......	2.2	......
4	......do	10.8	11.0	12.5	12.5	20.0	19.7	3.5	3.6	9.8	10.4	2.9	2.5
5	2 gm. $MgCO_3$	5.9	......	6.1	......	18.0	......	2.4	......	7.0	......	1.0	......
6	......do	5.9	5.9	8.0	7.0	18.0	18.0	2.7	2.5	6.8	6.9	1.4	1.2
7	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$.	5.9	......	7.0	......	17.5	......	3.0	......	5.5	......	1.4	......
8	......do	5.8	5.8	7.4	7.2	18.0	17.7	2.5	2.7	7.5	6.5	1.2	1.3
	SOY BEAN CAKE MEAL, 2 GRAMS.												
9	None	18.5	......	15.0	......	21.5	......	4.5	......	16.0	......	45.0	......
10	......do	15.0	16.7	17.5	16.2	22.0	21.7	4.6	4.5	14.0	15.0	45.0	45.0
11	2 gm. $CaCO_3$	14.5	......	19.0	......	22.0	......	5.0	......	23.5	......	68.0	......
12	......do	15.0	14.7	20.0	19.5	20.0	21.0	5.5	5.2	21.0	22.2	66.0	67.0
13	2 gm. $MgCO_3$	16.5	......	8.8	......	19.0	......	5.4	......	18.0	......	4.0	......
14	......do	20.0	18.2	9.8	9.3	19.5	19.2	3.5	4.4	20.0	19.0	3.9	3.9
15	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$.	14.0	......	16.5	......	19.5	......	3.0	......	13.5	......	4.3	......
16	......do	22.0	18.0	10.5	13.2	19.5	19.5	2.5	2.7	16.5	15.0	4.3	4.3
	AMMONIUM SULPHATE, 1.2 GRAMS.												
17	None	2.0	......	4.0	......	17.0	......	1.4	......	3.5	......	4.6	......
18	......do	2.2	2.1	4.1	4.0	16.8	16.9	1.5	1.4	3.3	3.4	5.0	4.8
19	2 gm. $CaCO_3$	3.8	......	9.0	......	16.0	......	1.7	......	3.6	......	8.3	......
20	......do	5.5	4.6	9.2	9.1	15.0	15.5	1.5	1.6	3.9	3.7	7.3	7.8
21	2 gm. $MgCO_3$	.5	......	3.2	......	17.0	......	1.4	......	3.1	......	1.7	......
22	......do	.5	.5	3.0	3.1	16.5	16.7	1.4	1.4	3.1	3.1	1.9	1.8
23	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$.	.8	......	3.1	......	16.5	......	1.9	......	3.0	......	2.1	......
24	......do	.9	.8	3.3	3.2	17.0	16.7	1.8	1.8	3.0	3.0	2.0	2.0

From these data it is shown that the nitrification of dried blood was stimulated by calcium carbonate in soils Nos. 292 and 448, while no effects were produced in soils Nos. 288, 329, and 428; magnesium carbonate, on the other hand, proved toxic in Nos. 292, 288, 428, and 485, while in soils Nos. 329 and 448 it was without effect.

In the nitrification of soy bean cake meal we find that calcium carbonate produced but little effect in soils Nos. 292, 329, and 428, but was stimulating in soils Nos. 288, 448, and 485; the addition of magnesium carbonate produced stimulation in soil Nos. 292 and 448, was without effect in No. 428, while in soils Nos. 288 and 485, particularly the latter, notably toxic effects were produced.

In the nitrification of ammonium sulphate, results somewhat different were found. Calcium carbonate caused considerable stimulation in soils Nos. 292, 288, and 485, while in Nos. 329, 428, and 448 it was without effect. Magnesium carbonates, on the other

hand, proved toxic in soils Nos. 292, 288, and 485, and exerted practically no effects in each of the other soils.

In general, the simultaneous addition of calcium and magnesium carbonates produced effects similar to those produced by magnesium carbonates alone. In the soils and with the nitrogenous materials with which calcium carbonate proved most stimulating, magnesium carbonate was most markedly toxic. Soy bean cake meal was on the whole more readily nitrified than dried blood or ammonium sulphate notwithstanding the fact that only 165 milligrams of nitrogen was added in the soy bean cake meal, while 265 milligrams was added in dried blood and 240 milligrams in the ammonium sulphate. Neither is this fact to be attributed to the lack of ammonification in the case of dried blood, for by referring to previous ammonification experiments it will be seen that vigorous ammonification of dried blood took place in these soils, and furthermore, the amount of ammonia formed in each instance was greatly in excess of the nitrate. It is possible that too great concentration of ammonium sulphate was used for the best action of the nitrifiers. On the whole the nitrifying power of these soils is rather low, especially in the case of ammonium sulphate.

NITRIFICATION IN MANGANIFEROUS SOILS.

There are considerable areas of highly manganiferous soils on Oahu on which pineapples make very poor growth. In order to throw some light on nitrification in these soils, a series of experiments was carried out, using both calcium and magnesium carbonates. The results are shown in the following table:

Effects of calcium and magnesium carbonates on nitrification in manganese soils.

[Average amount in milligrams of nitrate nitrogen per 100 grams soil.]

Soil portions.	Carbonate added.	Soil No. 514.	Soil No. 515.	Soil portions.	Carbonate added.	Soil No. 514.	Soil No. 515.
	DRIED BLOOD, 2 GRAMS.						
1, 2	None	28.0	6.5	7, 8	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$	4.2	1.1
3, 4	2 gm. $CaCO_3$	37.0	5.2				
5, 6	2 gm. $MgCO_3$	3.5	1.1				
	SOY BEAN CAKE MEAL, 2 GRAMS.						
9, 10	None	61.0	26.4	15, 16	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$	13.5	4.1
11, 12	2 gm. $CaCO_3$	94.0	11.4				
13, 14	2 gm. $MgCO_3$	15.2	4.1				
	AMMONIUM SULPHATE, 1.2 GRAMS.						
17, 18	None	7.8	3.5	23, 24	2 gm. $CaCO_3$ + 2 gm. $MgCO_3$	2.4	1.1
19, 20	2 gm. $CaCO_3$	6.1	1.7				
21, 22	2 gm. $MgCO_3$	2.5	1.1				

The above data show that nitrification takes place in the manganiferous[1] soils quite as vigorously as in other island soils. The addition of calcium carbonate caused stimulation in the nitrification of dried blood and soy bean cake meal in soil No. 514, while in soil No. 515 it caused a reduction in the nitrification of each of the materials used. In each instance magnesium carbonate proved markedly toxic, and the addition of calcium carbonate did not overcome the toxic effects.

EFFECTS OF CALCAREOUS AND DOLOMITIC LIMESTONES ON NITRIFICATION.

The following series of experiments show the effects produced by pulverized limestone and dolomitic limestone in comparison with chemically pure calcium and magnesium carbonates.

Effects of calcium and magnesium carbonates and different limestones on nitrification.

[Average amount in milligrams of nitrate nitrogen per 100 grams soil.]

Soil portions.	Carbonate added.	Soil No. 485—Soy-bean cake.	Soil No. 516—Soy-bean cake.	Soil No. 292—Dried blood.	Soil portions.	Carbonate added.	Soil No. 485—Soy-bean cake.	Soil No. 516—Soy-bean cake.	Soil No. 292—Dried blood.
1, 2	None	44.5	13.0	9.6	9, 10	2 gm. limestone ($CaCO_3$)	60.0	10.0	9.3
3, 4	2 gm. $CaCO_3$	67.0	9.0	11.8	11, 12	2 gm. dolomite	70.0	13.1	10.3
5, 6	2 gm. $MgCO_3$	3.8	5.3	8.7					
7, 8	1.1 gm. $CaCO_3$+0.9 gm. $MgCO_3$	8.2	6.4	9.8					

Again it will be seen that calcium carbonate produced notable stimulation in the nitrification of soy bean cake meal in soil No. 485 and a retardation in No. 516. Magnesium carbonate again proved toxic in each instance, and the simultaneous addition of calcium and magnesium carbonates, in the amounts in which they occur in dolomite, produced effects similar to those of magnesium carbonate alone. When we come to the natural limestones, it will be seen that both the calcareous and dolomitic limestones produced effects very similar to those produced by calcium carbonate, and that no toxicity was produced in any case by the dolomitic limestone.

DISCUSSION.

From the experiments above recorded, it has been shown that calcium carbonate produced only slight stimulation of the ammonification of dried blood and soy bean cake meal in most of the soils studied. Magnesium carbonate, on the other hand, caused considerable stimulation in the ammonification of dried blood in a majority of the soils, while in a number of instances the effects on the ammonification of soy bean cake meal were negligible. In two soils only,

[1] See Hawaii Sta. Bul. 26 (1912), p. 55.

Nos. 335 and 461, magnesium carbonate produced toxic effects, and in the former the effects on the ammonification of dried blood were quite similar to those found from the use of the sandy soils from California.[1] But the smaller amounts of ammonia, that accumulated in the presence of magnesium carbonate, were not entirely due to the volatilization of ammonia. Hence, magnesium carbonate was toxic to some extent. No antagonism to the action of magnesium carbonate was produced by calcium carbonate, but since magnesium carbonate is more soluble than calcium carbonate we are not justified in affirming that no significance is to be attached to the lime-magnesia ratio. It seems probable, however, that the stimulating effects produced by magnesium carbonate, on the one hand, and the toxic effects on the other, were not due to variations in this ratio, but rather to changes in the concentration of magnesium and to double decompositions.

Magnesium carbonate stimulated the ammonification of dried blood in soils which already contained abnormally high amounts of magnesium, and, since ammonia is an available form of nitrogen, the application of magnesium carbonate to these soils might prove of practical value to crops. The magnesium in these soils exists largely as hydrous silicates, and though present in much greater amounts than calcium, is considerably less soluble in dilute acids and water, and consequently is probably not present in the soil solutions in amounts equal to those of calcium. It has been shown in a different connection that Hawaiian soils have a remarkably high absorptive power for a number of chemical substances. Potassium, for instance, is fixed in relatively large amounts, but at the same time corresponding amounts of calcium and magnesium are set free.

Now, in all the soils studied above, save No. 335, it is probable that a soluble salt of magnesium (in this instance magnesium carbonate and the salts of organic acids formed through the reaction between magnesium carbonate and the organic acids set free in the decomposition of the materials added), would become fixed through double decomposition, thus setting free potassium, sodium, and calcium. Therefore, the concentration of the several constituents in the soil moisture would become greatly changed as a result of adding magnesium carbonate. Hence, the effects produced by magnesium carbonate on ammonification are probably complex, and can hardly be attributed wholly to its acting on the bacteria directly. The fact that magnesium carbonate caused no loss of ammonia in most of these soils is probably due to their fixing power for ammonia, which has been shown elsewhere to be unusually high. In every instance, except one, no antagonism to the effects produced by magnesium carbonate, either stimulating or toxic, resulted from the addition of

[1] Loc. cit.

calcium carbonate. Therefore, the effects on ammonification produced by magnesium and carbonates present a striking contrast, and the effects produced by the former suggest that the amounts of soluble magnesium in soils exerts an important bearing on bacterial action.

While magnesium carbonate produced striking effects on ammonification, the question loses much of its practical significance for the reason that magnesian limestone exerted effects similar to those brought about by calcium carbonate, and in no way comparable to those produced by magnesium carbonate.

When we come to nitrification, it was found that calcium carbonate produced stimulation in a few instances, although the increases in nitrate, with one exception, were small.[1] The carbonate content of most of these soils is low, usually less than 0.1 per cent. Generally calcium carbonate has been found to stimulate nitrification in soils which contain such low amounts of carbonate. That such is not the case in Hawaiian soils is probably due to the large amounts of aluminum and ferric hydrates present, which substances take the place of calcium carbonate in maintaining the neutral conditions as shown by Ashby.[2]

In the case of magnesium carbonate, it was found that nitrification was hindered in soils Nos. 485, 514, and 515. The toxic effects were striking, but as in the case of ammonification, practically no antagonism was found between calcium and magnesium carbonates. Dolomitic limestone, however, produced effects very similar to calcium carbonate, causing stimulation in the soils in which calcium carbonate produced stimulation, and no effects in the soils that were unaffected by calcium carbonate.

It is not possible to explain fully the action of magnesium carbonate. It seems probable, however, that the nitrifying floras of different soils would be affected differently by magnesium carbonate, being toxic in some soils and without effect in others. It will be observed by reference to the table (p. 45) that the effects produced in certain soils by magnesium carbonate depended on the nitrogenous material being acted upon. This may be accounted for, in part, by the dried blood and soy bean cake meal having reacted unequally on the growth of those organisms which feed upon ammonia and nitrates. It was observed, for instance, that wherever magnesium carbonate was added a more abundant growth of molds took place. The organic acids formed in the decay of the materials must have reacted with the magnesium carbonate, leading to the formation of different organic salts, the specific effects of which are not known. It is

[1] Peck has shown that calcium carbonate produces considerable stimulation on nitrification in some of the sugar lands of the islands. See Hawaiian Sugar Planters' Sta., Agr. and Chem. Bul. 37 (1911).
[2] Loc. cit.

probable, however, that compounds of unequal solubility and of different action on the nitrifying bacteria were formed. If so, the differences observed in the nitrification of dried blood and soy-bean cake in one and the same soil were probably due, in part at least, to causes of this nature, since the nonnitrogenous constituents of these materials differ greatly. The dried blood contained a very small nitrogen-free extract, while the soy bean cake meal contained more than 30 per cent.

That dolomite produced effects unlike those of magnesium carbonate is probably due to the insoluble nature of this material, and also to the fact that dolomite reacts with acids of various sorts less energetically even than calcium carbonate. Consequently the magnesium contained in the dolomite probably remained insoluble during the time of the experiments.

In the first series of experiments on ammonification (p. 39) Baker's analyzed magnesium carbonate, having the composition $3MgCO_3.Mg(OH_2)3H_2O$, was used. As already pointed out, considerable stimulation was produced by this material in two heavy clay soils, which stimulation was slightly greater than that produced by corresponding amounts of calcium carbonate, while the effects in a sandy soil were pronouncedly toxic. It was suggested that these results were in part referable to the magnesium hydrate contained in this material. With the hope of eliminating magnesium hydrate from consideration, Merck's reagent magnesium carbonate, which is claimed to be free from the hydrate, was used in all the subsequent experiments. This material, however, probably also contained some magnesium hydrate, as a saturated solution of it proved to be of approximately the same alkalinity to methyl orange as a saturated solution of Baker's carbonate. It is not certain, however, that the stimulation given to ammonification, as compared with that of calcium carbonate, or the toxicity found in certain instances, was due to alkalinity.

In the experiments previously reported by the writer using sandy soils from California,[1] Baker's magnesium carbonate was used, and marked toxicity, both to ammonification and nitrification, was produced. It was found, for instance, that the addition of 0.1 per cent magnesium carbonate proved toxic to a considerable degree and that 0.4 per cent produced practically maximum toxicity. Subsequently it has been found that the alkalinity of water extracts obtained by leaching portions of one of these soils after ammonification had ensued for seven days, bore no relation to the toxic or stimulating effects produced by magnesium or calcium carbonates, respectively. On the other hand, C. B. Lipman[2] has shown from

[1] Loc. cit.
[2] Centbl. Bakt. [etc.], 2. Abt., 32 (1911), pp. 58–64.

experiments with a similar sandy soil from California that considerable stimulation to ammonification was produced by the addition of 0.4 per cent sodium carbonate, a compound generally considered to be strongly alkaline. It seems probable, therefore, that the alkalinity of the magnesium carbonate was not responsible for the toxic effects in the California soils.

The difficulties inherent in the determination of actual acidity in soils are very great. Hawaiian soils, as stated above, generally have a high absorptive power for soluble bases, and the adsorptive effects and other physical phenomena that are produced when a soluble salt is added to a soil must be considered. In view of all these facts it is difficult to determine whether the greater alkalinity of the magnesium carbonate was a factor to be considered in the above experiments. It is true, however, that Hawaiian soils are potentially basic and hence it seems improbable that magnesium carbonate would cause greater stimulation to bacterial action than calcium carbonate on account of its being more actively alkaline, especially when the latter was added in amounts equal to 2 per cent of the soil. It is possible that excessive alkalinity had something to do with the marked toxicity to nitrification noted in certain instances.

SUMMARY.

(1) The pasture and forest lands of Hawaii, the soils used for aquatic crops, and most other island soils not subjected to frequent tillage contain very small amounts of nitrate but considerably larger amounts of ammonia.

(2) The uncultivated soils are capable of supporting vigorous ammonification of dried blood, but are toxic to nitrification.

(3) Nitrification takes place in Hawaiian soils after aerated conditions have been maintained for a period of several months, but not immediately following tillage. Ammonification is also stimulated by tillage.

(4) The inactive state of nitrification in the uncultivated soils is not due to the absence of the nitrifying organisms or acidity.

(5) Sterilization in the autoclave and burning failed to bring about conditions favorable to nitrification, but burning caused a splitting off of large amounts of ammonia.

(6) The beneficial effects to crops produced by burning refuse is probably due in considerable part to the formation of ammonia.

(7) The plants growing on the uncultivated soils probably absorb nitrogen largely in the form of ammonium compounds.

(8) Partial sterilization of Hawaiian soils stimulates ammonification for a short time, usually about two weeks, followed then by a retardation in ammonification. Nitrification is inhibited tem-

porarily by partial sterilization, but later on regains its activity, due possibly to reinoculation with air-borne organisms.

(9) Reinoculation of the partially sterilized with untreated soil did not overcome the stimulation to ammonification, but stimulated nitrification.

(10) A permanent increase in the available nitrogen (nitrate and ammonia) was effected by partial sterilization in certain soils, while in others the effects were very temporary. In the latter instances it is possible that nitrate and ammonia consuming organisms gained the ascendancy toward the close of the experimental periods, and that ammonification was partially inhibited by the too great accumulation of the products of bacterial action.

(11) Two-tenths per cent of toluol and carbon bisulphid were equally as effective as 4 per cent.

(12) It is believed that both the aeration and partial sterilization of Hawaiian soils bring about stimulation in bacterial action through effects produced on the colloidal soil films, but continued aeration is the more effective. The protozoan theory appears to be of doubtful application to these soils.

(13) Calcium carbonate produced considerable stimulation in the ammonification of dried blood and soy bean cake meal in certain soils; in others, only slight effects. Magnesium carbonate, on the other hand, produced marked stimulation in a number of instances. In two soils only, magnesium carbonate was toxic to ammonification. Dolomitic and calcareous limestones produced effects similar to those produced by calcium carbonate.

(14) In certain soils calcium carbonate stimulated nitrification, while in others no effects were produced. Magnesium carbonate, on the other hand, was toxic to nitrification in a majority of the soils studied.

(15) Nitrification was found to be equally as active in the manganiferous and titaniferous soils as in the other soils studied, but magnesium carbonate was especially toxic in these soils, and was more toxic to the nitrification of soy bean cake meal than of dried blood.

(16) Dolomitic and calcareous limestones produced similar effects on nitrification, bringing about stimulation in the soils in which calcium carbonate produced stimulation and no effects in the soils that were unaffected by calcium carbonate.

(17) The application of calcareous and dolomitic limestones will probably produce similar effects on the availability of nitrogen in Hawaiian soils, but regarding the effects of the burnt limes, further experiments are necessary before conclusions can be drawn.

(18) Positive conclusion can not be drawn concerning the effects of the lime-magnesia ratio on ammonification and nitrification in soils.

The evidence to date, however, points to the probability that this ratio exerts very little, if any, influence on bacterial action in the usual soil. The concentration of magnesium salts in the soil moisture, on the other hand, probably has an important influence on bacterial action.

(19) The experiments recorded in this bulletin emphasize the importance of maintaining the best aeration possible. This can not be done profitably without the rotation of crops, including green manuring. The exceedingly high clay content of much of the cultivated lands causes the soil to be very heavy, and to pack after rains, so that aeration becomes poor. By increasing the humus content aeration will be increased, drainage facilitated, and bacterial action stimulated. Thus, the plant food will become more available, deeper rooting of crops be encouraged, and their ability to withstand the effects of drought be greatly increased. No system of soil management in Hawaii can be judicious or permanent without the rotation of crops and the maintenance of humus.

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HAWAII AGRICULTURAL EXPERIMENT STATION,

J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 38.

EFFECT OF FERTILIZERS ON THE PHYSICAL PROPERTIES OF HAWAIIAN SOILS.

BY

WILLIAM McGEORGE,

Assistant Chemist.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

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HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *August 1, 1914.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 38 of the Hawaii Agricultural Experiment Station, a paper dealing with the Effect of Fertilizers on the Physical Properties of Hawaiian Soils, by William McGeorge, assistant chemist of this station. The peculiar constitution of Hawaiian soils makes a study of the physical properties of these soils one of unusual importance. In this paper there are described systematic experiments made to determine the effect of various fertilizers upon capillarity, percolation, flocculation, cohesion, apparent specific gravity, vapor pressure, and hygroscopic moisture. Before it is possible to reach a thorough understanding of Hawaiian soils it has been found necessary to study them from all standpoints. The paper is a contribution to the knowledge of the physical properties of soils and particularly of the effect of fertilizers in other ways than as plant food.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

THE EFFECT OF FERTILIZERS ON THE PHYSICAL PROPERTIES OF HAWAIIAN SOILS.

INTRODUCTION.

It has been the custom in Hawaii since agriculture was first placed upon a commercial basis to stimulate crops with heavy applications of mineral fertilizers. This procedure has been maintained in spite of the fact that a majority of the soils are naturally well supplied with plant food, in some instances abnormally so.

Hawaiian soils are of such a nature that the maintenance of the best possible physical state is imperative. They are derived from the disintegration of basaltic lava, have since been impregnated with coral limestone in many of the lowlands and with large amounts of organic matter in the uplands, where the rainfall is high and the vegetation profuse. Being derived from highly basic rocks, the resulting soils are highly basic in composition. The silica content varies from 15 to 50 per cent, while the basic constituents, iron and aluminum, compose the major part of the remainder. The tendency of these metals to form hydrates or silicates, their influence upon the mechanical structure, drainage, climatic conditions, temperature, aeration, and above all the effect upon the moisture supply, are matters which demand the careful consideration of agriculturists in these islands.

Soil moisture is a prime factor in successful plant growth. It not only influences the physical condition but also acts as a vehicle for the transmission of plant food from the soil to the plant. Since all mineral and many organic substances are more or less soluble in water and since all dissolved material is known to affect the physical properties of the solvent, it may be concluded that the properties of soil moisture and also the physical condition of the soil are partially dependent upon the composition of the soil solution.

These physical properties include capillarity, percolation, flocculation, cohesion, apparent specific gravity, vapor pressure, and hygroscopic moisture. Although the laboratory determinations of these properties of a soil and of the effect of salts thereon have little direct practical value, since the soil in such cases is not in a natural state, and other conditions are abnormal, they may be useful for

studying the relationship of different soil types and the effect of fertilizers upon the physical factors influencing plant growth.

From previous work in this laboratory and the experiences of practical farmers, physical factors appear to play a large part in the fertility of Hawaiian soils. The effects of heat and volatile antiseptics, the action of lime, the high absorptive power for fertilizers, the difficulties in drainage, high cost of tillage, and the peculiar biological effects that ensue, seem to be very largely explainable on a physical basis and to be referable in part to colloids.

In view of the above facts, this station has devoted considerable time to investigations upon the physical properties of soils and the function of fertilizers, other than as a source of plant food, with special reference to the movement of soil moisture. It is quite generally conceded that no simple explanation of the influence of fertilizers upon the soil or the plant is possible.

SOIL TYPES.

As in previous investigations upon soils in this laboratory, those of widely differing chemical and physical characteristics were chosen. The following tables show the physical composition and properties of these types. In Table I will be found the mechanical composition as determined by sedimentation according to Hall.[1]

TABLE I.—*Mechanical analyses of the soils.*

Soil No.	Moisture.	Volatile matter.	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Fine silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
428	13.80	25.65	11.89	28.26	13.63	4.64	1.53	0.60
448	12.45	28.83	1.70	7.52	14.29	11.75	17.49	5.97
516	10.41	17.64	3.40	5.29	29.66	10.30	15.75	7.55
530	3.58	13.90	0.49		5.76	10.34	37.97	27.96
542	7.98	17.81	.81		31.26	13.39	17.79	10.96
573	12.26	20.44	1.50		31.48	19.10	11.93	3.29
574	7.60	13.96	.36	1.15	8.07	9.35	24.90	34.87

Of the above soil No. 428 is a dark-colored, highly organic, sandy soil from Glenwood, Olaa, Hawaii.

Soil No. 448 is a yellow silty sand from Hilo, Hawaii.

Soil No. 516 is a sample of manganiferous soil from the Wahiawa district, Oahu. It has a chocolate-brown color, silty texture, and maintains an excellent mechanical condition.

Soils Nos. 530 and 574 are samples of red-clay soils, the former of a light and the latter of a dark red color.

Soil No. 542 is a titaniferous soil of grayish red color and silty texture. Its physical condition is very similar to that of soil No. 516.

Soil No. 573 is a "dust" soil from the island of Hawaii. It is a dark-colored, highly organic silt, and very productive.

[1] The Soil. London, 1908, 2. ed., p. 51.

WATER CAPACITY OF SOILS.

Table II contains data illustrating the water capacities of these soils. Columns 4 and 5 show the percentage of water by weight and volume, respectively, required to saturate the soil, and columns 6 and 7 show the percentage by weight and volume required to saturate and fill interstitial spaces.

TABLE II.—*Water capacity of the soils.*

Soil No.	Weight of soil.	Volume of soil.	Percentage of water to saturate.		Percentage of water to saturate and fill spaces.	
			Weight.	Volume.	Weight.	Volume.
	Gm.	*Cc.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
428	150	177	61.1	51.8	64.8	55.1
448	150	168	60.2	53.7	64.3	57.5
516	150	176	66.3	56.5	71.6	61.0
530	150	132	43.7	49.6	48.3	54.7
542	150	160	61.7	57.8	63.7	59.7
573	150	189	76.3	60.7	76.3	60.7
574	150	161	50.3	46.9	62.6	58.3

SPECIFIC GRAVITY.

In Table III are given the specific gravities, both real and apparent, as well as the comparative volume occupied by 10 grams of these soils, excluding interstitial spaces, as determined upon the air-dry soils.

TABLE III.—*Specific gravity and volume of the soils.*

Soil No.	Real specific gravity.	Apparent specific gravity.	Volume occupied.	Soil No.	Real specific gravity.	Apparent specific gravity.	Volume occupied.
			Cc.				*Cc.*
428	2.4825	0.8474	4.03	542	2.8784	0.9375	3.48
448	2.5264	.8929	3.96	573	2.4454	.7936	4.09
516	2.8351	.8522	3.53	574	2.9087	.9316	3.46
530	2.9438	1.1363	3.40				

The foregoing data, while of more or less empirical nature, indicate the variation in physical properties of Hawaiian types of soil. The clays show the highest specific gravity, both real and apparent, the clay silts and silts next, while the sandy soils show the lowest. The opposite relation exists with regard to the volume and water capacity.

CAPILLARY MOVEMENT.

Upon the capillary movement of water more than upon any other physical factor is the plant dependent for successful growth. The functions of capillary water are many and involve the transmission of plant food from the soil to the plant, sustenance of the enormous evaporation during the heat of the day, and the like. By means of

this property water tends to distribute itself in all directions throughout the soil.

There may be properly considered to be three kinds of water present in soils—capillary, gravitation, and hygroscopic moisture. The capillary water is that which will not drain away but is held around the soil particles in the form of a moisture film; that is to say, there is an equilibrium between the forces of gravity and surface tension. However, capillary action is itself dependent upon and absolutely governed by such subfactors as density or gravity, viscosity, surface tension of the soil solution, and the size and composition (both organic and inorganic) of the soil particles.

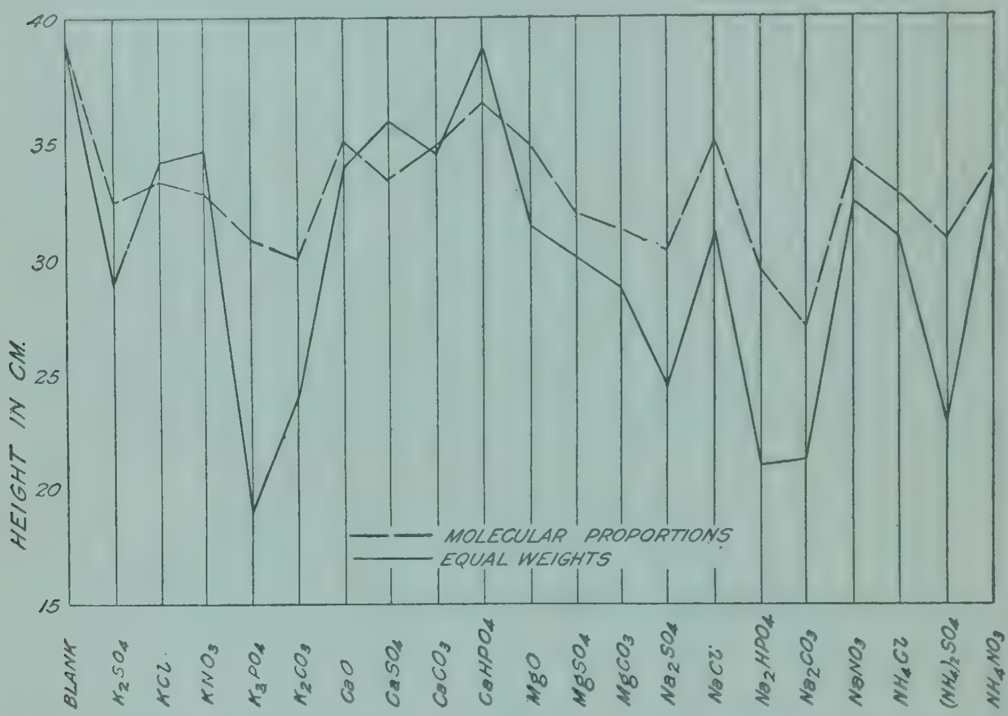

Fig. 1.—Relative capillarity following addition of salts in equal quantity and in molecular proportions.

When an object is removed from an immersion in water it retains a thin film upon its surface through the property of surface tension. In the same manner the soil particles are surrounded by a film or elastic membrane of water under a high pressure, the thickness varying within certain limits with the moisture content of the soil. As water is lost at the surface by evaporation or around the roots by absorption, there is a movement of water in the direction of increased tension, thereby tending to maintain an equal distribution of water. On the other hand, viscosity, acting in an opposite manner from surface tension, tends to retard the movement of water.

Water in soils is never pure, and all dissolved substances affect the degree of surface tension and viscosity of the solvent. Practically

all inorganic salts increase the surface tension of water while organic substances decrease it. On the other hand, the opposite relation exists with regard to viscosity. A series of experiments made at the Maryland Experiment Station [1] upon the surface tension of soil extracts show it to be considerably less than pure water. These and many other facts indicate the complexity of the application of theoretic principles to soils.

The capillary power of a soil is generally measured by the height to which water will rise in a soil column, although it may take place in all directions in soils and varies greatly according to the mechanical composition. The present study of capillarity was carried out in 1-inch glass tubes. Experiments were made not only with soils but also with silica sand and kaolin to ascertain the relation of these materials to soils. In all about 40 salts, fertilizer materials, and mixtures were used, including several organic manures. As a means of studying the effect of these salts, comparisons were made both when added in amounts proportional to their molecular weights and when added in equal amounts. Also measurements were made upon the variation in height to which the water would rise as affected by amounts of the salt varying from 0.06 to 6.66 per cent. In all cases the salts were added in small amounts.

Before presenting the data obtained in these experiments it is of interest to know the relative capillary activity of the soils in question. This is shown in Table IV, in which the figures were obtained by allowing the soil column to stand in about one-half inch of water for 78 days.

TABLE IV.—*Capillary rise of water in the soils.*

Soil No.	6 hours.	24 hours.	48 hours.	4 days.	5 days.	6 days.	7 days.	9 days.	11 days.	19 days.	32 days.	43 days.	78 days.
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
448	26.8	35.5	40.9	46.0	47.8	49.1	50.3	52.1	54.0	60.4	67.0	70.8	82.5
530	22.4	29.1	34.4	40.0	41.6	42.5	43.8	45.2	46.7	51.0	55.3	....	71.5
428	31.6	38.1	42.9	47.3	49.0	50.4	51.5	53.8	55.6	58.4	62.1	64.8	76.5
542	39.8	51.3	57.3	62.7	64.6	65.9	67.8	70.6	72.8	79.3	86.6	89.8	100.0
516	36.8	47.8	55.2	62.0	64.0	65.0	66.8	69.2	71.2	76.4	84.8	88.7	100.0
573	41.0	56.6	64.2	69.9	79.0	81.6	83.5	88.4	91.6	100.8	109.8	[1] 115.6	......
574	33.7	40.1	44.0	45.1	45.1	45.1	45.1	45.1	......	......	50.5	....	63.0

[1] Top of column.

The highly organic silty soil showed the greatest capillary rise, the clay soils least, while the sandy soils were intermediate.

In filling the tubes it is necessary to exercise considerable care in order to obtain a uniform mixture. This is made possible by projecting a long wire with a loop on the end into the tube and withdrawing it with a rotary motion.

[1] U. S. Dept. Agr., Weather Bur. Bul. 4 (1892), p. 16.

EFFECT OF VARIOUS SALTS IN MOLECULAR PROPORTIONS.

In studying the relations of the properties of salts of widely varying molecular composition it is imperative that a definite procedure be established. With this idea in mind the following curve (fig. 1, p. 10) is presented to show the difference in results obtained when the salts were added in equal amounts and in molecular proportions to soil No. 530. The former rate was 0.5 gram of basic oxid per 100 grams of soil and the latter as follows: Calcium carbonate, with a molecular weight of approximately 100, was chosen as a standard and added at the rate of 0.1 per cent, the other salts in greater or less amounts in proportion to their molecular weights.

From these curves it appears that as a whole the general property of a given salt is to affect the soil similarly whether added in equal weights or in molecular proportions. This is at least true of the capillary activity. The curves throughout are very similar and indicate that an increase in the concentration of the salt results in a diminished capillary activity.

This variation in activity as affected by increasing the concentration of the salt suggested a further study of the phenomenon, the results of which are given in Table V. Three types of soil and silica sand were used and the amount of salt used varied from none to 10 grams per 150 grams of soil.

TABLE V.—*Capillary rise as affected by increase in percentage of salt added.*

Salts.	Percentage of salt added.													
	Soil No. 530.							Soil No. 448.						
	0.00	0.06	0.16	0.33	0.66	3.33	6.66	0.00	0.06	0.16	0.33	0.66	3.33	6.66
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
CaO	37.3	34.1	33.2	32.2	33.5	18.7	12.5	30	35.0	36.5	36.0	37.0	34.0	29.0
$NaNO_3$	37.3	34.0	33.0	31.4	31.5	28.0	26.2	30	35.9	37.5	36.0	36.0	34.2	33.0
$(NH_4)_2SO_4$	37.3	31.9	31.8	28.6	25.5	21.1	21.4	30	37.6	35.3	36.0	34.2	31.0	29.8
$CaSO_4$	34.0	29.8	29.3	29.6	28.5	29.8	33.4	30	34.2	34.0	34.4	33.2	34.9	36.0
$CaH(PO_4)$	37.3	35.5	37.8	37.2	38.8	32.7	23.3	30	34.6	35.4	34.9	37.0	38.3	38.8
$CaCO_3$	37.3	35.4	33.0	31.8	33.8	35.3	38.0	30	33.3	32.7	32.2	34.1	35.9	38.5
K_3PO_4	34.0	31.0	29.0	25.9	26.0	21.7	13.9	30	34.9	33.6	33.0	31.4	31.1	24.0
KCl	34.0	28.7	27.8	29.0	28.0	26.5	26.0	30	34.2	35.0	34.4	35.0	36.3	34.6
$MgSO_4$	37.3	32.5	30.6	27.9	27.2	21.9	21.7	30	33.1	38.0	34.8	35.8	31.0	27.6
NH_4Cl	37.3	31.8	30.1	30.5	29.2	26.4	28.2	30	34.2	34.2	33.2	35.8	34.5	32.3
Na_2CO_3	37.3	28.4	24.3	21.4	18.7	9.4	6.9	30	32.6	33.1	30.1	29.5	17.4	14.8
K_2SO_4	37.3	32.3	31.8	30.0	28.2	26.0	25.8	30	36.4	36.9	36.4	34.8	31.5	31.5
Salts.	Soil No. 428.							Silica sand.						
CaO	29.0	37.0	36.1	38.0	40.0	33.2	26.2	9.8	7.3	6.4	6.9	7.0	20.0	28.8
$NaNO_3$	29.0	38.0	38.0	37.4	38.0	35.5	34.8	9.8	10.9	12.4	13.7	13.7	12.1	11.4
$(NH_4)_2SO_4$	29.0	37.9	34.9	34.6	35.0	33.5	29.4	9.8	12.2	12.6	12.6	12.6	12.3	12.0
$CaSO_4$	29.0	37.0	38.0	35.3	38.4	38.8	41.2	10.2	12.1	16.7	13.0	14.5	22.2	34.2
$CaH(PO_4)$	29.0	38.6	36.5	39.0	40.0	38.2	34.1	10.2	13.9	16.8	15.3	14.4	14.5	18.4
$CaCO_3$	29.0	37.7	38.0	35.2	36.3	38.9	37.6	10.2	16.6	14.9	18.3	20.5	27.4	32.6
K_3PO_4	29.0	38.8	37.9	37.0	36.5	33.1	24.2	10.2	12.4	14.6	16.6	15.7	11.6	12.2
KCl	28.6	36.8	36.8	36.6	36.9	37.1	35.2	9.8	10.9	13.5	11.9	12.4	14.1	16.1
$MgSO_4$	30.7	43.2	42.9	42.1	42.8	40.0	36.1	9.8	13.9	16.5	13.8	13.7	13.7	13.7
NH_4Cl	30.7	41.4	41.5	41.2	40.8	37.0	34.9	9.8	11.2	13.3	12.3	11.9	10.9	11.4
Na_2CO_3	30.7	36.8	37.7	36.1	39.0	34.4	25.4	9.8	15.9	16.4	14.7	15.7	17.5	17.5
K_2SO_4	29.0	37.2	35.7	34.7	35.2	35.2	35.0	9.8	13.7	14.1	14.5	13.9	13.0	16.2

Effect on soil No. 530.—The table shows that all the salts, with the possible exception of calcium phosphate, cause a regular decrease in rise of moisture with increase in concentration. Calcium phosphate, when added at the rate of 0.66 per cent, increases the activity.

Effect on soil No. 448.—Here again the effects of various salts seem to be related with few exceptions and the tendency is toward an increase in capillarity up to a certain concentration beyond which a further addition of the salt materially retards the rise of water. Exceptions to this rule are sulphate and carbonate of calcium, which, being difficultly soluble, would materially change the physical nature of the soil, and calcium phosphate, which, being a soluble salt, exerts a chemical effect.

Effect on soil No. 428.—The effects of salts upon the capillary activity in this soil are similar to those in the former except that the variation in moisture rise is greater. The soil, containing a greater percentage of sand, shows a higher rise in moisture.

Effect on silica sand.—Conditions in sand are ideal for measuring the effect of salts upon capillary action within certain limits, beyond which any further concentration gives misleading results. This is due to the filling of the pore spaces and the subsequent drawing up of moisture, caused by the salts as they become dissolved by the rising moisture, rather than to the action of the salt upon the activity of the film surrounding the grains. Taken as a whole the results with a concentration of salt below 3.3 per cent are very similar to those obtained with the sandy soil, the more marked variation being in the action of lime.

Apparently the most important inference to be drawn from the foregoing table is that the action of a high concentration of a salt in most instances only magnifies that of a small application.

With this fact determined it was decided that the salts should be used in as small amounts as possible and in amounts proportional to their molecular weights, thus more nearly approaching normal condition. The same molecular proportions as previously mentioned were used, while the fertilizing substances, such as mineral phosphates, blood, etc., were added at the rate of 0.1 per cent. The results given in Table VI show the relation of various salts to the rise of moisture in several of the dominating types of Hawaiian soils.

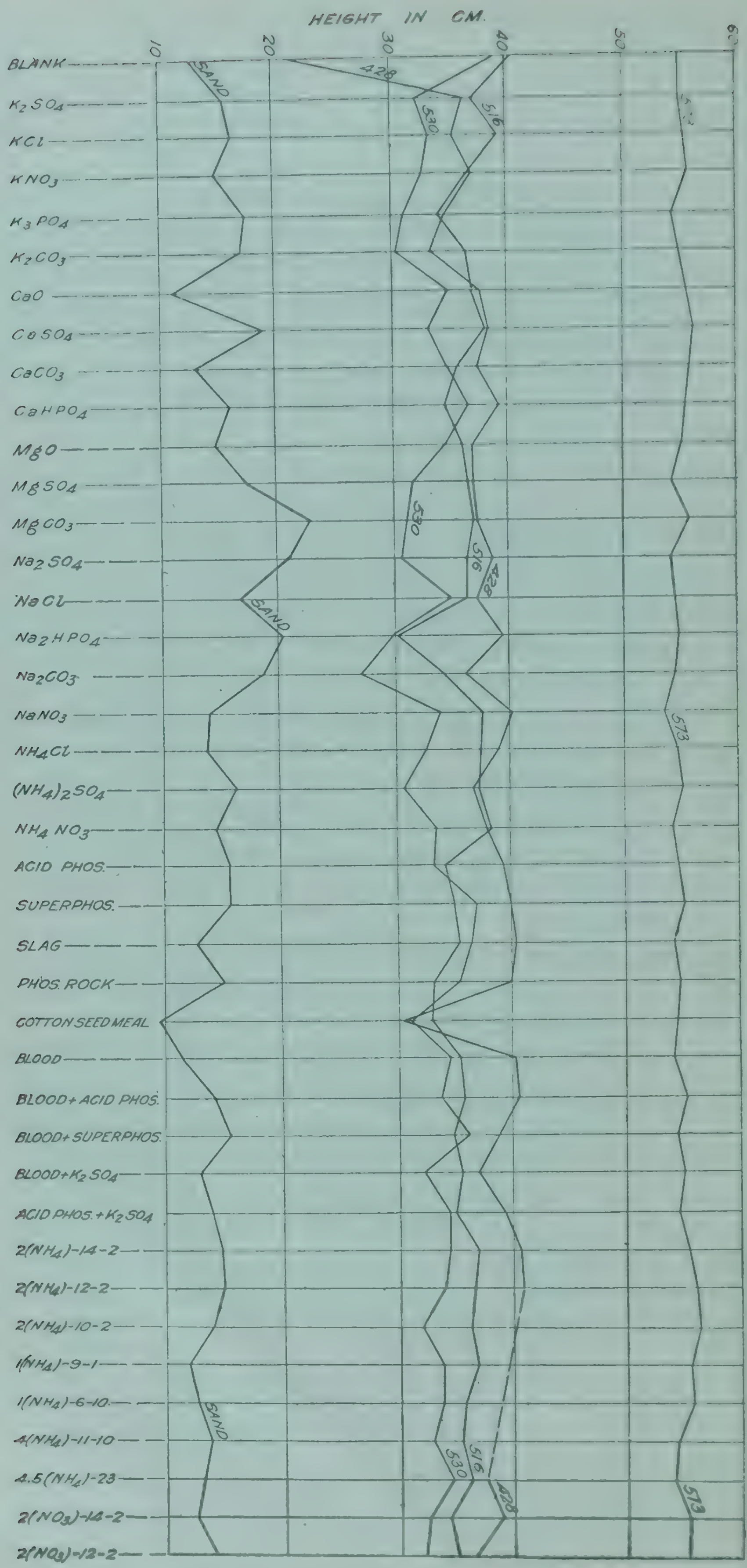

FIG. 2.—Effect of salts and fertilizers on capillary rise of moisture.

TABLE VI.—*Effect of various salts and fertilizers on capillarity, the salts being added in molecular proportions.*

Salts and fertilizers.	Weight per 200 gm. soil.	Soil No. 488.	Soil No. 530.	Soil No. 573.	Soil No. 516.	Soil No. 542.	Soil No. 428.	Kaolin.	Sand.
	Gm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
K_2SO_4	0.35	45.9	32.7	55.0	37.1	39.0	36.4	23.6	15.4
KCl	.15	46.6	33.4	55.3	39.0	39.1	35.1	25.4	16.2
KNO_3	.20	48.8	33.0	55.7	36.6	39.8	36.8	24.8	14.6
K_3PO_4	.42	42.1	31.1	54.2	34.1	36.7	34.7	23.3	17.5
K_2CO_3	.28	44.8	30.2	54.9	36.5	38.3	33.5	23.6	17.0
CaO	.11	46.6	35.0	55.5	36.9	40.7	37.8	26.1	10.8
$CaSO_4$	.27	46.3	33.4	56.2	38.3	41.4	38.3	21.9	18.9
$CaCO_3$	.20	47.6	34.8	56.0	35.8	42.9	37.6	25.2	12.8
$CaHPO_4$	.46	45.2	36.9	55.5	34.5	40.4	39.2	25.6	15.9
MgO	.08	47.5	34.9	55.1	36.2	40.3	37.0	24.7	14.5
$MgSO_4$	.24	47.2	31.9	54.2	36.5	40.4	37.0	25.0	17.5
$MgCO_3$	.70	44.3	31.3	55.8	37.1	41.7	37.0	26.5	23.0
Na_2SO_4	.28	45.4	30.5	54.0	36.4	38.7	38.6	22.1	21.1
$NaCl$	.12	46.5	35.2	54.5	36.4	41.3	37.1	23.6	16.7
N_2HPO_4	.72	45.9	29.7	54.7	30.0	36.9	39.6	20.2	20.3
Na_2CO_3	.21	45.0	27.2	54.4	34.7	40.0	36.2	21.2	18.7
$NaNO_3$	.17	45.5	34.2	53.7	38.0	40.4	40.3	22.8	14.0
NH_4Cl	.11	48.9	32.8	54.7	37.8	41.7	39.1	25.7	13.9
$(NH_4)_2SO_4$	.26	40.0	31.0	55.2	37.6	42.1	37.0	24.1	16.5
$(NH_4)NO_3$	.16	47.8	34.0	54.1	38.5	42.6	38.1	25.9	14.4
Acid phosphate	.20	45.4	33.9	54.9	34.5	40.2	39.5	26.0	15.8
Superphosphate	.20	46.5	37.4	55.2	35.2	40.5	40.0	25.7	15.8
Slag	.20	46.8	37.0	54.4	35.4	42.3	40.4	26.3	11.8
Phosphate rock	.20	45.7	35.7	54.9	33.6	42.0	39.9	....	15.0
Cottonseed meal	.20	44.6	31.4	54.8	33.4	37.7	31.4	26.6	9.5
Blood	.20	47.6	34.8	54.2	35.7	41.7	40.3	27.4	11.7
Blood and acid phosphate	.20	47.1	34.0	55.5	36.2	42.5	40.7	21.6	14.2
Blood and superphosphate	.20	47.4	36.8	54.5	34.9	42.9	39.0	26.4	15.8
Blood and K_2SO_4	.20	47.9	32.8	55.4	36.0	41.8	37.4	26.7	12.1
Acid phosphate and K_2SO_4	.20	47.9	35.4	54.6	35.1	40.7	39.8	26.5	14.2
$2(NH_4)$–14–2[1]	.20	47.1	35.0	55.9	37.5	42.4	41.1	24.6	14.8
$2(NH_4)$–12–2[1]	.20	47.7	34.5	56.6	37.3	42.3	41.5	24.7	15.3
$2(NH_4)$–10–2[1]	.20	46.8	32.8	56.9	37.1	40.7	....	26.8	14.1
$1(NH_4)$–9–1[1]	.20	47.5	34.3	55.8	37.5	42.0	....	25.5	12.2
$1(NH_4)$–6–10[1]	.20	47.6	34.3	55.9	36.1	41.2	....	24.6	12.9
$4(NH_4)$–11–10[1]	.20	46.3	33.5	54.6	35.9	40.9	....	26.6	13.9
$4.5(NH_4)$–23–0[1]	.20	47.7	35.5	54.6	37.0	40.9	38.3	23.9	13.3
$2(NO_3)$–14–2[2]	.20	47.6	33.3	56.0	35.0	41.9	39.6	26.4	12.8
$2(NO_3)$–12–2[2]	.20	46.8	33.0	55.9	35.8	40.8	37.5	24.5	14.2
Check	....	35.5	39.2	55.0	40.4	44.9	28.0	28.0	12.9
Time in hours	....	24	69	24	8	8	21	26	24

[1] Fertilizer mixtures supplying nitrogen (in ammonium sulphate), phosphoric acid, and potash in the order and proportions (percentages) given.

[2] Fertilizer mixtures similar to those referred to in footnote 1 except that nitrogen was supplied in sodium nitrate.

The accompanying curve (fig. 2) illustrates the effect of the fertilizers on capillarity more clearly than the table.

Effect on silica sand.—Here it is possible to explain most of the results by applying the known effects of salts upon the capillary activity of their solvents. Inorganic salts increase, and organic substances retard, the rise of water. The principal exceptions to this rule are calcium oxid and slag.

Effect on soils Nos. 428 and 448.—With these soils the rate of rise in moisture is quite rapid at first, decreasing to a very slow rise in a short time. All organic and inorganic substances added produced an increase in rate of capillarity within the time limits of the experiment. These soils have a coarse texture, contain a high percentage of organic matter and of hygroscopic and combined water, and hence indicate the relation of these properties to the capillary activity of soil extracts.

Effect on soil No. 573.—This soil, of all the types examined, possessed the greatest capillary activity and was least affected by the addition of salts. In fact, it may be assumed that the capillary activity of this soil is unaffected by the addition of outside agents as the results agree with the check within the limits of experimental error. In view of the above facts, a series of experiments was carried out in which the amount of salt added was doubled, the results of which agreed very closely with those reported above.

Effect on soils Nos. 516 and 542.—These soils are of very similar mechanical composition but belong to different chemical types. The data presented indicate that the clay tends to dominate the capillary activity of this type of soil in that the addition of all substances diminished capillarity.

Effect on soil No. 530.—The physical character of this type of soil is such that chemical agents would be expected to materially affect its texture. This theory is borne out in the diminished capillary activity noted in every instance.

Effect on kaolin.—The diminished capillarity observed in the study of the effect of salts on kaolin shows a direct relationship between this substance and clay soils.

Any attempt at classification of the above results according to theoretic considerations only indicates the complexity of applying any one theory to soils. More than one factor evidently enters into play to which it is necessary to give due consideration. That fertilizers do markedly affect capillarity is clearly shown. In using mixed fertilizers there is little variation in rise as related to variation in mixture. Those in which nitrates are used show decrease in water rise as compared with those containing ammonium sulphate.

EFFECT OF BASICITY ON CAPILLARITY.

Organic manures, as compared with the salts, retard the rise in the sandy soils and decrease the rise in others. As a rule, magnesium salts affect capillarity less than the calcium salts, potassium salts less than ammonium, sodium less than potassium, and the monobasic salts in most instances less than the dibasic. Among the monobasic salts, carbonates and phosphates show the lowest, sulphates next, nitrates next, and chlorids the highest water line.

With the phosphates the rise of moisture seems to depend upon the acidity or basicity of the salt. This may be observed by comparing data in Table VII with those in Table VI under the phosphates of lime. Here also the relation between acidity and rise of moisture is similar to that observed in the case of the potash salt.

TABLE VII.—*Showing effect of basicity on capillarity.*

	Weight added.	Height.		Weight added.	Height.
	Gm.	*Cm.*		*Gm.*	*Cm.*
KH_2PO_4	[1] 1.42	32.6	KH_2PO_4	0.5	32.6
K_2HPO_4	[1] .92	30.3	K_2HPO_4	.5	30.9
K_3PO_4	[1] .75	23.3	K_3PO_4	.5	29.0

[1] Equivalent to 0.5 per cent K_2O.

The easily hydrolyzable salts, phosphates and carbonates of the alkalis, show the lowest water table. However, they are much more active in organic soils due to their solvent action or chemical reaction with the organic matter present. These hydrolyzable salts also cause a swelling of the clay particles which, in Hawaiian soils, are partly composed of iron and aluminum hydrates and are conducive to the colloidal state, thus closing the pores, increasing friction, and lowering the rates of moisture rise.

PERCOLATION.

All moisture which passes below the surface, in excess of that held through capillary action or surface tension, is subject to the laws of gravity. The rate of movement, however, is dependent upon various factors, such as the size and composition of the soil particles, height of soil surface above water table, surface tension, and viscosity of the soil solution.

Percolation is quite generally held to be most rapid in soils in which capillary activity is greatest, decreasing with height of column, and is faster in wet soils than in dry soils. Clay, of course, offers the greatest physical resistance to the passage of water and the resistance varies with the degree of aggregation of the clay particles.

The rate with which water will pass downward, then, depends upon the physical state of the soil and this in turn varies with the arrangement of the soil particles. Both of these properties, however, are affected by the nature of the soil solution, percolation decreasing with increase in concentration.

For studying the effect of fertilizers upon this property of soils 1-inch glass tubes containing soil columns of about 30 centimeters were fitted up as in studying the capillary activity. These tubes were connected with a constant supply reservoir which maintained a 1-inch head of water in the tubes, and the water passing through the soil was measured at intervals. The totals of these measurements are given in Table VIII.

TABLE VIII.—*Percolation as affected by salts and fertilizers.*

Salts and fertilizers.	Soil No. 530.	Soil No. 573.	Soil No. 428.	Soil No. 516.	Salts and fertilizers.	Soil No. 530.	Soil No. 573.	Soil No. 428.	Soil No. 516.
	Time of experiment.					Time of experiment.			
	6 days.	7 days.	2¾ days.	4 days.		6 days.	7 days.	2¾ days.	4 days.
	Cc.	*Cc.*	*Cc.*	*Cc.*		*Cc.*	*Cc.*	*Cc.*	*Cc.*
Potassium sulphate	1,757	1,316	9,212	2,312	Magnesium sulphate	1,838	1,413	2,349	3,404
Potassium chlorid	3,543	1,265	5,300	4,123	Blank	8,687	1,628	......	[1] 7,086
Potassium phosphate	2,602	1,546	4,044	3,077	Sodium phosphate	1,765	1,253	3,545	3,293
Calcium oxid	3,824	1,555	2,985	4,851	Sodium carbonate	2,021	1,787	3,601	2,633
Calcium sulphate	940	1,939	2,134	5,635	Sodium nitrate	4,481	1,189	3,445	1,649
Calcium carbonate	661	1,564	2,516	4,569	Ammonium chlorid	4,162	1,452	5,038	3,355
Calcium phosphate	1,902	1,484	2,795	5,489	Ammonium sulphate	488	1,530	6,612	2,987
Magnesium oxid	2,008	1,504	2,166	5,093					
	7 days.	7 days.	40 hours.	3 days.		7 days.	7 days.	40 hours.	3 days.
	Cc.	*Cc.*	*Cc.*	*Cc.*		*Cc.*	*Cc.*	*Cc.*	*Cc.*
Superphosphate	1,688	1,940	2,568	1,581	Potassium sulphate and acid phosphate	3,491	1,321	2,693	4,631
Slag	4,784	1,588	3,256	3,632	$2(NH_4)$-14-2 [3]	2,305	1,618	1,945	4,060
Phosphate rock	1,990	1,675	2,546	3,902	$1(NH_4)$-9-1 [3]	3,685	1,636	3,852	2,847
Cottonseed meal	2,432	1,443	1,924	4,659	$4(NH_4)$-11-10 [3]	2,763	1,331	1,365	3,239
Blood	1,892	1,456	4,027	3,656	$4.5(NH_4)$-23-0 [3]	3,198	1,381	2,076	4,826
Blood and acid phosphate	1,476	1,567	2,012	3,324	$2(NO_3)$-14-2 [4]	3,745	1,480	2,044	5,006
Blank	5,865	1,710	11,936	[2] 7,226	Acid phosphate	3,209	1,649	1,308	2,456
Blood and potassium sulphate	4,753	1,423	3,526	1,715					

[1] Stopped after 2¾ days.
[2] Stopped after 2 days.
[3] Fertilizer mixtures supplying nitrogen (in ammonium sulphate), phosphoric acid, and potash in the order and proportions (percentages) given.
[4] Fertilizer mixture similar to those referred to in footnote 3 except that nitrogen was supplied in sodium nitrate.

A glance at this table clearly indicates the complexity of the study of the passage of water through soils. It is quite generally conceded that those soils in which capillary activity is greatest offer the least resistance to the passage of water. Soil No. 573 fails to lend support to this theory, as does also No. 516. In these soils the capillary activity is greatest, while they offer much greater resistance to the passage of water than the sandy soils. Even the heavy clay soil offers less resistance than No. 573.

As a whole the calcium salts cause less resistance than magnesium salts, ammonium less than potassium, chlorids less than sulphates in clay soils, but the sulphates least in organic soils. Mixtures in which sodium nitrate is used cause less resistance to flow of water than where ammonium salts were used.

Soil No. 530.—All the salts and fertilizers added to this type retarded the percolation of water. There is a slight relation between the degree of resistance and the flocculating power of the salts. As a rule the most deflocculated samples were among those that offered the greatest resistance and vice versa, as was found by examining

the soils at the completion of the experiments. The organic manures resist the flow also but when mixed with mineral fertilizers the resistance is less. The data taken from daily observations, not indicated in the table, show that the passage of water in practically all the tubes decreased steadily from day to day after the salts became diffused throughout the soil and the clay began to swell. This applies only to soils Nos. 530 and 573.

Soil No. 573.—Percolation through this soil was very slow and regular. Like capillary activity, salts had very little effect upon it. The amount of water passing through the tubes was less on the last day of the experiment than on the first day. There is practically no clay present in this soil, so that the action of the salts is probably upon the organic matter. This soil is the only one in which any salt increased the rate of flow. These salts were calcium sulphate, sodium carbonate, and superphosphate. Sodium nitrate strongly retarded percolation.

Soil No. 428.—In this instance it was not possible with the equipment available to maintain a constant head of water, due to the large volume which would percolate during the night. All the materials used at first decreased the rate of percolation but the daily rate increased steadily, for which reason the series was not carried out so completely as in the two previous soils. This increase was probably due to a washing out of the substances added. The action of sodium carbonate and sodium nitrate was very similar and unlike the effects in the above organic soil. The organic manures resist percolation quite strongly. The calcium and magnesium salts offer the greatest resistance, sodium salts next, ammonium salts next, and potash salts the least.

Soil No. 516.—This soil, owing to its mechanical condition and low organic content, offers little resistance to percolation of water. The effect of adding any agent is to decrease the flow. However, the results obtained indicate that some soils are capable of restoring their equilibrium, as is shown by the fact that the depression of the first day became less as diffusion became more complete. The dibasic salts offer less resistance to percolation than the monobasic.

FLOCCULATION.

The rôle of flocculation in soils is one of considerable importance in a study of soils such as occur in these islands. The red clay is a type possessing an unusual tenacity and requires judicious handling to prevent puddling and to maintain the colloidal clay in the best physical condition. Various investigators, recognizing that a soluble salt will bring about the flocculation of the suspended material in a turbid liquid, have studied the relation of this to the improve-

ment of the texture in heavy soils. Indeed this is said to be the primary function of lime, which is one of the most universally applied soil amendments.

The above studies indicate that the maintenance of a crumb structure is seriously menaced by the presence of even a trace of certain compounds. Hence flocculating or deflocculating agents alter the soil structure. The latter not only destroy the compound aggregates but also bring about a diffusion or swelling of the colloidal clay. This results in a closing of the pore spaces, shutting out the air, development of acid conditions, and menacing the whole cycle of normal soil transformations.

Since it is conceded that the best physical state, known as a crumb structure, is due to flocculation of the smaller grains into aggregates, the conclusion is obvious that the study of conditions conducive to the formation of a colloidal state and the relation of salts to this state may be of considerable local application.

As a means of studying this property of Hawaiian clay a sample of highly puddled soil was chosen, one in which the clay would remain in suspension for weeks. A stock suspension of this soil sufficient for all experiments was prepared, so that a suspension of known concentration would be available. The degree of flocculation, to a certain extent, depends upon the relation of the amount of clay in suspension to the strength of the flocculating agent.

Normal solutions were prepared of all the salts used in previous experiments, except the slightly soluble ones, in which case saturated solutions were made. By a series of preliminary experiments those salts having a negative or deflocculating effect were eliminated. These include potassium and sodium phosphates and carbonates. Secondly, salts causing a flocculation of the clay but not sufficiently soluble to form a normal solution were eliminated. These include the oxid, carbonate and sulphate of calcium and the oxid and carbonate of magnesium.

The comparisons were made in glass cylinders of 400 cubic centimeters capacity in which were placed 2 cubic centimeters of normal salt solution, 10 cubic centimeters of clay suspension, and 188 cubic centimeters of water, making a total of 200 cubic centimeters. This mixture was shaken and allowed to settle. In the case of the stronger flocculants this proved too great a concentration, hence the experiments were repeated with a much weaker solution. The results are given in Table IX.

TABLE IX.—*Showing relative rate of flocculation by acids and their salts.*

Salt or acid.	Time required for flocculation.		Salt or acid.	Time required for flocculation.	
	$\frac{1}{100}$-normal solution.	$\frac{1}{800}$-normal solution.		$\frac{1}{100}$-normal solution.	$\frac{1}{800}$-normal solution.
	Hours.	*Hours.*		*Hours.*	*Hours.*
H_2SO_4	1	6	NaCl	120	....
$Al_2(SO_4)_3$	1	1	NH_4Cl	103	....
$CaSO_4$	9	....	HNO_3	1	2
$MgSO_4$	4	100	$Ca(NO_3)_2$	1	72
K_2SO_4	105	....	$Mg(NO_3)_2$	2½	144
Na_2SO_4	120	....	KNO_3	48	....
$(NH_4)_2SO_4$	147	....	$NaNO_3$	150	....
HCl	1	3	NH_4NO_3	72	....
$CaCl_2$	1	29	H_3PO_4	1½	192
$MgCl_2$	3	76	$CaHPO_4$	1½	240
KCl	165	....	CH_3COOH	15	....

These results agree to a certain extent with the findings of other investigators. They indicate a relationship between the valency of the salt and its flocculating power. The most active salt is aluminum sulphate, a trivalent salt and one which is highly hydrolyzed. The divalent calcium and magnesium salts of nitric, hydrochloric, and sulphuric acids are next, while the monovalent salts of sodium, potassium, and ammonium are least active. The acids are stronger than any of their divalent salts but the trivalent salt, aluminum sulphate, is stronger than any of the acids. Nitric acid is the strongest, hydrochloric second, and sulphuric third. Likewise the nitrates and chlorids are stronger than the sulphates. This indicates that the degree of flocculation is related both to the acidity and the basicity. Phosphoric and acetic acids cause much less flocculation than the other acids.

Thus far no investigator has been able to satisfactorily explain this phenomenon, although various theories have been advanced. The explanation is probably to be found within the realm of colloid chemistry. Hall and Morrison suggest that some physicist must first arrive at a satisfactory explanation of Brownian motion. They[1] have recently suggested the possible presence of free alkali derived from the partial hydrolysis of the suspended material and that flocculation ensues when these are neutralized. Hilgard assumed a chemical hydration of the fine particles of clay when in suspension which when lime was added became dehydrated, causing a flocculation of the soil particles.

Regarding the composition of soil colloids little is known. While many authors have assumed them to be inorganic it is probable that being characteristic of the states of matter from which they are formed and not of any particular substance, they may be partly organic. Free[2] suggests that organic colloids may coat the soil particles with thin films.

[1] Jour. Agr. Sci., 2 (1907), No. 3, pp. 244–256.

[2] Jour. Franklin Inst., 169 (1910), No. 6, pp. 421–438; 170 (1910), No. 1, pp. 46–57.

There is practically no doubt that colloids exist in Hawaiian soils. The physical properties indicate such to be the case. A chemical analysis of the clay shows it to be primarily a silicate of iron and aluminum with a probability of the hydrates being present also. Noncoagulable clay, by analysis, shows a higher percentage of iron and silica and less alumina than the coagulable clay. This indicates that part of the iron exists in the form of ferric hydrate.

While the chemical composition may affect the nature of the colloids and the degree of flocculation the phenomenon itself is physical. The relation is between the composition and nature of the colloidal film surrounding the clay particle and its degree of surface tension. The effects of any added acid or salt is to alter the nature of the film probably through penetration or chemical action, thereby increasing or decreasing the surface tension, depending on the nature of the added substance, and increasing or decreasing the degree of flocculation. Some authors maintain that the salt or acid actually replaces bases within the colloid, thereby altering its composition, while others maintain that it only alters the film and by washing upon a filter with water the clay will revert to its original colloidal state. This latter contention seems to apply best to the conditions found to exist in Hawaiian soils. At all events the flocculation of Hawaiian clay is influenced as follows:

(1) Most acids and neutral salts, especially electrolytes, increase the degree of flocculation.

(2) Highly dissociated acids are the strongest coagulants, and the less dissociated acids act more or less in proportion to their degree of ionization.

(3) Electrolytes of greater valency possess a greater degree of flocculation than those of lesser valency.

(4) Most highly dissociated alkalis are strongest deflocculants, as are also the alkali salts of weak acids, such as phosphoric.

(5) Ammonium hydroxid is an exception, being only slightly ionized, but at the same time it is the strongest deflocculant.

(6) The degree of flocculation depends upon the strength or valency of the anion as well as of that of the cation.

COHESION.

The film of moisture around soil particles imparts to them cohesion by which the particles are bound together. As the moisture content decreases surface tension of the film increases and the particles are drawn together. Hence, in a clay soil where shrinkage is greatest, there results the formation of cracks. There is a definite moisture content at which tenacity of the soil particles is at a minimum, the texture is best for culture, and the whole environment is most conducive to the best plant growth. The factors bringing about such

conditions depend upon the mechanical composition, the organic matter present, and the presence or absence of certain soluble substances.

As a means of measuring the effect of salts upon this cohesive property of Hawaiian soils, the procedure described by the Bureau of Soils was used.[1] In this procedure a mechanical shaker having a screening apparatus and operated by a motor is used to insure a uniform packing of the soil. By means of this apparatus a cup was filled with the soil and by means of a penetrating apparatus the weight necessary to cause a steel cone-shaped needle to penetrate a fixed depth was determined. While the results so obtained are not directly comparable with results obtained by other investigators, due to slight differences which may result from the construction of the apparatus, they are comparable among themselves.

In Table X are shown the salts used in the experiments and the penetration with varying moisture contents, 1,500 grams of soil being used in making the determinations. After each penetration water was added, as shown in the table, well mixed with the soil and allowed to stand one hour before repeating the penetration test. Five penetrations were made on each cup of soil and the average taken. The cup was refilled for further penetrations, repeating these some three or more times at each moisture content if there was any undue variation. Water was added up to the point at which it was impossible to work the soil. Salts were added at the rate of 15 grams per 1,500 grams soil, or 1 per cent of salt. Portions were taken from each cup for moisture determination.

TABLE X.—*Effect of salts on cohesion in soils under various percentages of moisture.*

SOIL NO. 573.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.
Per ct.	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*
13.43	25.25	......	......	......	......	......	......	......	......	......	......	......	......
16.67	27.25	15.61	26.25	15.85	26.35	15.55	29.20	15.43	28.60	14.55	28.55	16.94	27.30
20.65	28.85	19.14	26.25	17.62	27.55	17.60	30.15	17.87	27.50	18.05	29.95	19.26	27.35
23.14	26.90	21.94	25.15	20.40	28.8	21.22	29.15	20.54	27.7	21.10	27.40	21.70	27.15
25.11	25.00	24.72	25.20	22.96	28.25	23.02	26.35	23.15	27.05	23.78	25.25	24.07	27.30

SOIL NO. 530.

3.66	50	3.90	50.0	......	......	......	......	......	......	......	......	......	......
6.78	48.75	7.14	46.9	8.35	51.5	7.47	48.2	7.47	50.6	8.56	52.75	7.47	49.2
9.98	46.25	11.43	49.3	11.61	48.6	10.50	51.75	11.69	51.5	12.56	51.5	11.02	58.75
12.66	49.30	14.84	55.2	14.60	49.7	14.44	53.5	15.02	53.45	14.87	49.9	13.88	61.0
16.40	51.50	16.86	52.0	17.10	52.2	17.42	52.45	17.33	49.7	18.00	50.4	16.76	69.0
19.30	48.5	21.68	51	21.60	47.0	19.86	47.45	20.20	48.55	20.31	47.95	......	......

[1] U. S. Dept. Agr., Bur. Soils Bul. 50 (1908).

TABLE X.—*Effect of salts on cohesion in soils under various percentages of moisture*—Continued.

SOIL NO. 516.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.	Moisture content.	Penetration weight.
Per ct.	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	*Gm.*
10.95	38.5	......	......	......	......	......	......	......	......	......	......	......	......
15.14	36.65	14.19	35.95	12.33	39.4	13.09	35.90	11.49	35.3	10.19	37.15	12.18	35.6
18.54	36.3	17.77	37.15	15.96	38.3	16.51	35.9	15.01	39.8	13.98	39.30	15.62	36.9
21.26	38.45	21.16	35.0	19.12	36.35	19.11	36.2	18.22	37.45	17.46	36.5	18.79	35.65
24.13	37.5	23.67	33.3	21.71	40.05	22.46	39.55	21.86	39.5	20.90	36.95	21.25	37.45
26.71	33.9	26.11	32.55	24.77	35.60	24.95	34	22.21	37.45	22.79	36.1	23.37	37.05

SOIL NO. 428.

11.23	37.85	......	......	......	......	......	......	......	......	......	......	......	......
15.11	35.40	12.97	34.6	14.44	35.1	13.14	36.6	......	......	......	......	14.18	37.05
17.96	31.6	16.42	35.95	18.39	32.95	17.30	35.25	......	......	......	......	18.08	33.95
18.50	31.75	19.10	35.0	20.00	34.5	19.50	34.4	......	......	......	......	20.76	34.7
21.90	30.3	21.98	33.1	22.75	31.25	22.42	33.05	......	......	......	......	23.25	35.25
25.33	28.4	24.96	31.15	26.62	30.5	25.34	32.75	......	......	......	......	25.87	32.1

Soil No. 573, given in Table X, is the silty organic soil. The weight required for penetration increased at first and then decreased with increase in moisture content, reaching a minimum at 25 per cent, which is apparently the optimum moisture content for this type of soil. The effect of the addition of salts is to increase the weight necessary for penetration at the optimum moisture content, that is, salts increase the cohesion of the soil particles. This is especially true of lime. The cohesion apparently does not vary with change in moisture content in the presence of sodium carbonate.

Soil No. 530.—Table X shows the relation between moisture content and cohesion for the predominating red type of clay soil. Nineteen per cent moisture represents the point above which it is impossible to work with this type, due to the fact that the soil will not pass through the screen used in the apparatus. The figures obtained show an optimum moisture content of about 10 per cent if conclusions are to be drawn from the theories advanced by previous investigators. However, 10 per cent is rather low for this type of soil and it is probable that the optimum point for plant growth is above the range of the experiment. The cohesion of this soil decreases at first, then increases up to 16 per cent moisture, followed by a second decrease. The remarkable effect of sodium carbonate (and this would apply in more or less degree to all deflocculating agents) is clearly shown in the table. Regarding the effect of other salts, little can be concluded from the data at hand. That they do affect cohesion there is no doubt, but it is impossible to definitely classify these effects.

Soil No. 516.—Here again it was not possible to determine exactly the optimum point, but 26 per cent water is probably very close to this stage. The effect of increasing the moisture content is to decrease cohesion to a certain point, followed by an increase, then descending as the optimum moisture content is approached. Potassium sulphate decreases cohesion while the rest of the salts apparently increase this property in varying degree.

Soil No. 428.—The effect of varying the moisture content of this soil differs from that observed with the other soils in that the decrease in cohesion is regular and rapid as a result of increasing the moisture content up to the optimum point. The effect of salts is to increase the cohesion of this type of soil. This fact was found to be true in every instance. Owing to a lack of sufficient soil, ammonium sulphate and sodium nitrate were not used.

Throughout this work care was exercised to subject each cup of soil to the same procedure. Penetrations were made at equal distances from the center of the cup, the weight was allowed to fall through equal heights, and similar methods used throughout. Even with these precautions it was difficult to obtain closely agreeing results from a clay soil, but very concordant results were obtained from the other types.

APPARENT SPECIFIC GRAVITY.

Closely related to cohesion and bearing directly on the swelling of soils on wetting and shrinking and cracking upon drying is the apparent specific gravity, the relation between the weight of a soil and the volume it occupies. This property has been supposed to be at a minimum at the optimum moisture content of the soil. Like all physical properties it is subject to modification and is more or less affected by the same factors that affect the cohesive power.

The same apparatus used for penetration experiments was used for the determination of the apparent specific gravity. The data were obtained by dividing the weight of the soil in the container by its volume. The results are given in Table XI.

TABLE XI.—*Effect of salts and moisture content on apparent specific gravity.*

SOIL NO. 573.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.
Per ct.		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*	
13.43	0.7017	......	......	......	......	......	......	......	......	......	......	......	......
16.67	.6745	15.61	0.6807	15.85	0.6842	15.55	0.6868	15.43	0.6587	14.55	0.6693	16.94	0.6605
20.65	.6359	19.14	.6305	17.62	.6605	17.60	.6544	17.87	.6394	18.05	.6394	19.26	.6412
23.14	.6000	21.94	.5921	20.40	.6254	21.22	.6193	20.54	.6061	21.10	.5894	21.70	.6079
25.11	......	24.72	.5438	22.96	.5842	23.02	.5710	23.15	.5674	23.78	.5587	24.07	.5649

TABLE XI.—*Effect of salts and moisture content on apparent specific gravity*—Cont'd.

SOIL NO. 530.

Check.		Potassium sulphate.		Calcium oxid.		Superphosphate.		Ammonium sulphate.		Sodium nitrate.		Sodium carbonate.	
Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.
	Per ct.		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*		*Per ct.*
3.66	1.0284	3.90	1.0368	......	......	......	......	......	......	......	......	......	......
6.78	1.0596	7.14	1.0737	8.35	1.0745	7.47	1.0622	7.47	1.0500	8.56	1.0517	7.47	1.0087
9.98	1.0886	11.43	1.0973	11.61	1.1135	10.50	1.0851	11.69	1.0956	12.52	1.1052	11.02	1.0517
12.66	1.1096	14.84	1.1289	14.50	1.1509	14.44	1.1079	15.02	1.1043	14.87	1.1079	13.88	1.0394
16.40	1.1017	16.86	1.1114	17.10	1.1070	17.42	1.0912	17.33	1.0605	18.00	1.0693	16.76	1.0079
19.30	.9640	21.68	.9745	21.60	.9096	19.86	.9447	20.20	.8789	20.31	.9184	......	......

SOIL NO. 516.

10.95	0.8035	......	......	......	......	......	......	......	......	......	......	......	......
15.14	.8973	14.19	0.9026	12.33	0.8886	13.09	0.8859	11.49	0.8666	10.19	0.8684	12.18	0.8587
18.54	.9096	17.77	.9219	15.96	.9351	16.51	.9158	15.01	.9245	13.98	.9236	15.62	.9035
21.26	.8219	21.16	.8140	19.12	.8886	19.11	.8570	18.22	.8982	17.46	.9166	18.79	.8833
24.13	.7403	23.67	.7517	21.71	.8035	22.46	.7781	21.86	.8219	20.90	.8307	21.25	.8324
26.71	.6675	26.11	.6833	24.77	.7210	24.95	.7140	22.21	.7543	22.79	.7552	23.37	.7912

SOIL NO. 428.

11.23	0.7394	......	......	......	......	......	......	......	......	......	......	......	......
15.11	......	12.97	0.7403	14.44	0.7517	13.14	0.7245	......	......	......	......	14.18	0.8386
17.96	.7464	16.42	.7342	18.39	.7245	17.30	.7166	......	......	......	......	18.08	.7657
18.50	.7175	19.10	.7079	20.00	.7079	19.50	.7008	......	......	......	......	20.76	.7298
21.90	.6737	21.98	.6780	22.75	.6789	22.42	.6701	......	......	......	......	23.25	.6929
25.33	.6403	24.86	.6377	26.62	.6684	25.34	.6623	......	......	......	......	25.89	.6666

In soil No. 573 specific gravity decreases regularly with increase in moisture content up to the optimum both in the untreated soil and in those treated with salts. The effect of salts is not striking but in some cases increases, in others decreases, the apparent specific gravity.

In soil No. 530 the results are very similar to those obtained in the cohesion tests. This type shows an increase in specific gravity up to a maximum, above which point it decreases to what has been assumed to be the optimum point. Calcium oxid, superphosphate, ammonium sulphate, sodium nitrate, and sodium carbonate decrease the specific gravity, while potassium sulphate slightly increases it, differing considerably from their action on the previous soil.

With soil No. 516 the results are similar to those with No. 530 in that the apparent specific gravity increases with increase in moisture content to 18.5 per cent, beyond which it decreases to the optimum point. All salts affect this soil in the same manner, resulting in an increase in apparent specific gravity, sodium carbonate having the greatest effect.

Soil No. 428 shows the same relation between apparent specific gravity and moisture content as soils Nos. 516 and 530. The effect

of salts is very similar and also tends to increase this property to a slight extent.

The two physical properties of soils known as cohesion and apparent specific gravity are more or less dependent upon and governed by the same factors, and it is shown in the table that the effect of varying moisture contents and addition of salts is similar. Both reach a minimum at the point known as that of optimum moisture content, which is conceded to be the stage most favorable to plant growth. Hence these properties are of special significance in soil investigations.

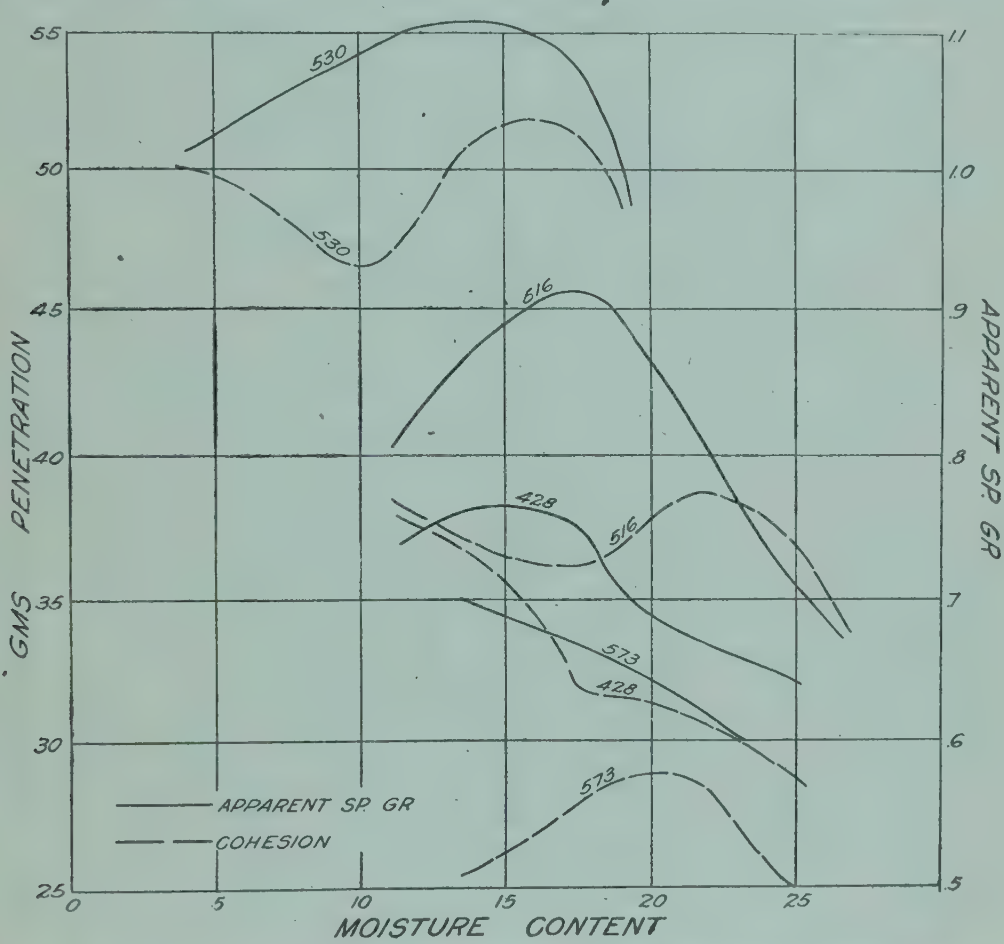

FIG. 3.—Relation between cohesion, apparent specific gravity, and moisture content of soils.

In classifying the Hawaiian types of soil according to these properties, the clay soil possesses the highest cohesive properties, the manganese silt next, the sandy soil third, while the lowest and hence the most easily cultivated is the silty soil, No. 573. The same relation applies also to the apparent specific gravity and is true not only at the optimum moisture content but also on the air-dry soils. The curve shown in figure 3 well illustrates the relationship existing between these two properties of Hawaiian soils. At the lower moisture contents the curves diverge considerably while above a given point they again follow similar lines.

VAPOR PRESSURE.

Comparatively little work has been done on the effect of soluble salts on vapor pressure of soils, i. e., the rate of evaporation. Theoretically salts should increase the surface tension of solvents and thereby lower their vapor pressure and hence increase the water-retaining capacity of the soil. The study made of this property indicates that this theory apparently applies to Hawaiian soils.

As a means of measuring this property of soils ordinary weighing bottles were used. Twenty gram lots of soil with which the various salts had been mixed were placed in these bottles, 12 cubic centimeters, or 60 per cent, of water was added to each and then allowed to stand one week in the open air. Weighings were made at this stage, following which all the samples were placed in the same desiccator with calcium chlorid and weighings were again made after one week. The results are given in Table XII.

TABLE XII.—*Effect of salts on vapor pressure.*

Salts and fertilizers.	Amount added.	Soil No. 530.		Soil No. 573.		Soil No. 428.		Soil No. 516.	
		Water retained.		Water retained.		Water retained.		Water retained.	
		In air.	In desiccator.	In air.	In desiccator.	In air.	In desiccator.	In air.	In desiccator.
	Gm.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Sodium carbonate	0.10	65.3	46.0	39.4	20.9	39.2	31.9	43.7	29.5
Sodium nitrate	.09	71.2	55.5	50.0	33.2	44.1	38.8	46.8	31.4
Magnesium oxid	.04	64.2	43.6	45.7	26.0	44.4	38.2	42.9	24.4
Calcium carbonate	.10	66.2	42.7	41.0	21.6	44.3	35.3	44.9	26.9
Calcium phosphate	.23	52.8	21.0	42.7	15.2	43.0	30.7	45.7	....
Calcium oxid	.06	58.6	29.7	44.8	24.4	39.8	31.5	44.8	28.3
Potassium phosphate	.21	51.4	26.9	41.3	19.3	42.4	25.4	35.9	15.2
Potassium sulphate	.17	62.7	42.9	48.1	33.6	39.5	31.2	37.8	17.5
Ammonium sulphate	.13	73.9	61.3	41.7	26.4	43.0	31.7	35.6	17.4
Potassium chlorid	.08	50.2	28.2	45.8	21.7	40.2	40.5	44.8	33.8
Superphosphate	.10	63.3	43.3	44.7	27.4	42.8	25.7	38.4	25.6
Acid phosphate	.10	77.0	60.2	45.8	28.5	41.3	15.3	37.3	22.7
Cottonseed meal	.10	32.5	8.0	41.5	9.7	43.3	23.1	43.6	27.4
Blood	.10	42.6	16.2	36.1	7.2	48.7	28.6	43.8	29.9
Acid phosphate and blood	.10	44.0	9.5	31.2	4.3	41.4	24.8	40.7	22.5
Potassium sulphate and acid phosphate	.10	58.2	25.6	40.3	16.2	49.2	30.3	44.1	28.6
2 (NH_4)-14-2[1]	.10	36.5	10.2	39.3	8.3	41.2	19.3	40.6	20.4
1 (NH_4)-9-1[1]	.10	37.8	10.8	35.7	9.6	38.7	17.5	37.2	20.9
2 (NO_3)-14-2[1]	.10	59.6	41.3	45.3	25.6	57.2	22.8	42.4	28.6
Check	....	48.0	24.6	36.3	15.3	37.0	17.8	35.4	22.1

[1] Fertilizer mixtures containing nitrogen, phosphoric acid, and potash in the order and proportions (percentages) indicated; nitrogen from ammonium sulphate in the first two, from sodium nitrate in the third.

These figures indicate that the effect of salts upon vapor pressure in soils is one of considerable importance. Salts act upon Hawaiian soils more or less according to theory. The major part of them increase the water-holding power in all four soils. Organic substances increased evaporation in soils Nos. 530 and 573, but had the opposite effect upon Nos. 428 and 516. These results also show that the form of nitrogen used in mixed fertilizers bears a definite relation to the vapor pressure. Those in which sodium nitrate was used show a

much greater capacity for holding moisture. In fact, sodium nitrate itself has the most striking effect on all types of soils. There is no apparent classification of the results according to the changes in surface tension which should theoretically result through the addition of the salts.

HYGROSCOPIC MOISTURE.

When a soil has been dried in the air and then is exposed to a moist atmosphere it will reabsorb moisture. The amount which it is able to take up depends upon several factors, such as mechanical composition, presence or absence of organic matter and its state of decay, temperature of the air, and presence of colloidal clay and ferric and aluminum hydrates. This form of moisture, while it is not in itself able to support normal plant growth, may materially assist in sustaining vegetation during drought. Some investigators claim it to be of absolutely no service to plants.

Hawaiian soils, owing to their high humus and ferric hydrate content, possess a very high hygroscopic coefficient. Of the series used in this study the sandy soil was lowest, as would be expected, but even in this case the hygroscopic moisture is high in comparison with normal sandy soils, due to its high organic content.

Table XIII shows the comparative moisture-absorbing power of the types studied. From these data we are led to conclude that, due to the abnormal physical properties of Hawaiian soils, the size of particles is not the primary factor in determining its hygroscopic properties, although surface exposed is an important factor.

The data presented in this table were obtained by exposing a very thin layer of soil in a saturated atmosphere for 144 hours, after which the total moisture was determined. Soil No. 428 having the least exposed surface, the highest percentage of organic matter, and the highest moisture content in the air-dry soil, has the least hygroscopic power. The clay soil, No. 530, has the most exposed surface, the largest percentage of ferric hydrate, the lowest moisture content in air-dry form, the least organic matter content, and next to the lowest absorbing power. But soils Nos. 516 and 573, a manganese silt of high iron content and an organic silt, respectively, soils very dissimilar in chemical composition and physical properties, have the highest absorbing power, with the balance in favor of the manganese soil.

TABLE XIII.—*Percentage of hygroscopic moisture absorbed in 144 hours.*

Soil No.	Hygroscopic moisture.
	Per cent.
530	19.32
573	21.59
428	15.56
516	24.04

Table XIV shows the effect of salts upon the hygroscopic power of soils. That this property should be affected by the addition of fertilizers was to be expected, since most salts possess this property themselves to a greater or less extent, and it is only natural that they should impart it to soils. These experiments were conducted by exposing a thin layer of soil to a saturated atmosphere in two large containers. Conditions were made as nearly similar as possible, but blank samples of soil were exposed in each as checks. Salts were well mixed with a bulk of soil at the rate of 0.5 per cent of salt, and weighings made from this bulk. Samples were exposed for 48 hours and total moisture determined in the air bath at 105° C.

TABLE XIV.—*Effect of salts and fertilizers on hygroscopic moisture.*

Salts and fertilizers.	Soil No. 530.	Soil No. 573.	Soil No. 428.	Soil No. 516.	Soil No. 542.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Original moisture content of soils	3.17	10.84	9.87	5.54	4.12
Potassium sulphate	17.21	19.35	14.80	21.40	18.45
Calcium oxid	16.78	19.80	14.05	21.30	16.10
Acid phosphate	16.76	17.88	13.90	19.90	16.42
Ammonium sulphate	17.08	18.70	15.53	21.15	20.30
Sodium nitrate	17.28	24.80	17.45	22.20	20.10
Sodium carbonate	17.64	24.20	15.80	21.30	17.95
Check	16.35	18.90	14.55	20.70	16.11
Calcium sulphate	16.26	20.81	13.70	21.20	17.30
2 (NH_4)-14-2 [1]	16.90	20.20	14.70	21.50	16.80
2 (NO_3)-14-2 [1]	16.56	22.00	15.08	20.50	17.06
Superphosphate	17.07	20.30	13.80	21.40	16.70
Potassium sulphate and acid phosphate	16.50	18.50	14.35	21.80	16.60
Sodium chlorid	18.95	32.00	22.02	30.00	22.50
Check	16.35	18.58	14.58	21.10	16.18

[1] Fertilizer mixtures containing nitrogen, phosphoric acid, and potash in the order and proportions (percentages) named; nitrogen from ammonium sulphate in the first, from sodium nitrate in the second.

The effect of adding salts upon the ferruginous clay is to increase the hygroscopic power in every instance, except where calcium sulphate is added, in which case there is very little variation. As a matter of fact the general tendency of all the salts on the different types is to increase this property of soils, and in cases where there is a decrease it is almost negligible. Sodium chlorid, being itself a hygroscopic salt, imparts the highest absorbing power to the soil, while the lowest is effected by addition of acid phosphate.

SUMMARY.

The foregoing pages contain data obtained from an extensive study of the physical properties of Hawaiian soils and the effect of fertilizers upon these properties. It is evident that agents which influence the mechanical condition are many and complex. It has also been clearly demonstrated that the addition of salts or fertilizing materials affects the structure of the soil.

It is impossible to predict in all cases the degree to which any one or all physical properties will be influenced by the addition of a fer-

tilizer, since this depends primarily upon the mechanical composition of the soil, the nature of the organic matter, and probably upon certain factors which are at present unknown. However, within certain limits, the effect of adding a larger application of a salt only magnifies that of a smaller application. This suggests that the measurement of the physical effect may be just as accurately, and possibly more accurately, determined than the chemical effect. The measurement of a normal application of fertilizer through a chemical analysis of the soil is practically impossible.

Capillarity is diminished in clay soils by the addition of salts but increased in sandy soils. Also this property is more active in silts than in sandy or clay soils, being slowest in the latter.

The percolation of water is most rapid in sandy soils and slowest in types the particles of which are most likely to swell. Fertilizers considerably increase the resistance to percolation. The theory that soils of greater capillary activity offer the least resistance to percolation of water does not apply to Hawaiian soils.

Salts increase or diminish the size of the soil aggregates. This is of no small importance in the use of fertilizers.

The cohesion of the soil particles in most instances is increased by the addition of salts. This is also true of the apparent specific gravity. However, there are too many exceptions to make any definite statement.

The hygroscopic moisture is increased by the addition of salts, with but very few exceptions.

The vapor pressure is lowered in most instances, but can not be explained from a consideration of the surface tension of the added salts.

Acknowledgments are due and thanks hereby extended to Dr. W. P. Kelley for valuable suggestions and for interest shown throughout this investigation.

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J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 39.

THE BIOCHEMICAL DECOMPOSITION OF NITROGENOUS SUBSTANCES IN SOILS.

BY

W. P. KELLEY,

Chemist.

UNDER THE SUPERVISION OF

STATES RELATIONS SERVICE.

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[Under the supervision of A. C. TRUE, Director of the States Relations Service, United States Department of Agriculture.]

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[1] Resigned October 27, 1914.

LETTER OF TRANSMITTAL.

HAWAII AGRICULTURAL EXPERIMENT STATION,
Honolulu, Hawaii, September 14, 1914.

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 39 of the Hawaii Experiment Station a paper on The Biochemical Decomposition of Nitrogenous Substances in Soils, by W. P. Kelley, chemist. More exact information is needed on the sources from which plants draw nitrogen for their growth. This bulletin contains the results of a study of the percentages of ammonia derived from the bacterial decomposition of various organic nitrogenous substances in soils. In six out of the eight substances used in this study the basic diamino acid nitrogen was found to be more readily converted into ammonia than was the nitrogen of other groups.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director States Relations Service,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATION.

THE BIOCHEMICAL DECOMPOSITION OF NITROGENOUS SUBSTANCES IN SOILS.

INTRODUCTION.

The chemical changes produced in the nitrogenous substances of soils by bacteria are of great importance. As is well known, the end products are ammonia, nitrate, and free nitrogen, but the intermediate steps of the change, which are probably of great importance, are only imperfectly understood. It appears that proteins undergo progressive decomposition in soils similar to that which takes place in animal digestion, and it is highly probable that ammonification is preceded by hydrolysis. From the investigations of Schreiner et al.[1] it has been shown that small amounts of protein and nucleoprotein cleavage products are widely distributed in soils; and Löhnis and Green[2] recently found from ammonification experiments with flesh meal that in the early stages of the action greater amounts of ammonia were obtained by distilling a 1 per cent hydrochloric acid extract with caustic soda than with magnesia. They held that the caustic soda decomposed soluble hydrolytic products (amino acids) split off by the bacteria. At a later stage, when the amino acids had presumably been more completely decomposed, the yields of ammonia by the two methods were more nearly equal.

It is probable that not all of the nitrogen in a given protein is equally susceptible to ammonification[3] and that different proteins undergo decomposition at different rates, even when all other conditions are equal. In ammonification experiments, for example, it is seldom that more than from 50 to 60 per cent of the nitrogen added is recovered as ammonia, and different nitrogenous substances yield ammonia at greatly different rates. As is well known, the main portion of the nitrogen in soils occurs in organic forms and has previously existed as vegetable protein. After the organic matter of soils has been acted upon by bacteria for a time a residue, rich in nitrogen, and commonly called humus, is left, which undergoes further decomposition at a very slow rate. Moreover, the rate of formation of ammonia from humus appears to depend to some extent on the conditions under which the humus was itself formed. Generally acid

[1] U. S. Dept. Agr., Bur. Soils Buls. 53, 74, 80, 83, 88.
[2] Centbl. Bakt. [etc.], 2. Abt., 37 (1913), pp. 534–562.
[3] See Jodidi, Iowa Sta. Research Bul. 9 (1912).

humus, or humus formed under anaerobic conditions, is thought to decompose more slowly than neutral humus. Thus it seems that conditions arise during the course of bacterial action which tend to check the process, or else some of the constituents of proteins are more difficult of hydrolysis and decomposition than others.

Previous investigations on proteins throw much light on this subject. It is known that proteins are composed of a number of amino acids and that different proteins undergo hydrolysis by acids, alkalis, and enzyms at different rates, yielding varying amounts of the several amino constituents. From limited study on the subject it seems that bacterial and enzymatic action bring about similar hydrolysis of proteins, with the important difference that the products of hydrolysis are subject to decomposition by bacteria. During the course of such action certain amino acids are split off more rapidly than others. Abderhalden and Reinbold [1] found, for example, that in the tryptic digestion of edestin from cotton seed, 97.6 per cent of the tyrosin had been split off at the end of 2 days, while only 7.4 per cent of the glutaminic acid had been hydrolyzed.

From previous work in this laboratory [2] it has been shown that Hawaiian soils contain relatively greater amounts of amid and smaller amounts of basic (diamino acid) nitrogen than the vegetable proteins. From this it has been suggested that a study of the group changes produced under the action of bacteria might throw important light on both the availability of, and the nature of bacterial action on, nitrogenous fertilizers. Various factors, such as the degree of aeration, the acidity of the medium, the carbohydrates present, the synthesis of proteins in the body cells of the bacteria, the absorption of organic nitrogen compounds in varying degrees by plants, etc., so complicate the problem as to render very difficult an interpretation of the chemistry of bacterial action in soils. It has been suggested, however, that by also studying the rates of decomposition under varying conditions some light might be thrown on this question.

AMMONIFICATION UNDER VARYING CONDITIONS.

SERIES I—AMMONIFICATION IN SILICA SAND.

The materials used in this investigation contained the following percentages of nitrogen: Casein (Eimer and Amend), 12.40 per cent; dried blood, 13.29 per cent; soy bean cake meal, 8.28 per cent; cottonseed meal, 5.10 per cent; linseed meal, 5 per cent.

In order to insure maximum aeration the first series of tests was conducted with the use of silica sand. One gram each of the above nitrogenous materials and one gram of calcium carbonate were thoroughly mixed with 100-gram portions of sand in tumblers. Ten cubic

[1] Ztschr. Physiol. Chem., 46 (1905), pp. 159–175. [2] Hawaii Sta. Bul. 33 (1914).

centimeters of an infusion, made by shaking for ten minutes 200 grams of fresh soil, taken from the citrus orchard of this station, with 250 cubic centimeters of sterile water was then added to each beaker and thoroughly mixed with the contents. The beakers were covered with watch glasses and the mixtures incubated at 28° C. The ammonia was determined at intervals, as shown in the table, by three different methods. One portion was distilled directly with magnesia; three other portions were first shaken with 250 cubic centimeters of 1 per cent hydrochloric acid, allowed to stand for an hour, and then filtered. An aliquot of one of these, corresponding to 75 per cent of the material used, was made alkaline with magnesia and distilled, while aliquots of the other two portions were distilled with caustic soda. The results obtained were as follows:

Amount of ammonia formed in silica sand from different substances.

Period of incubation.	Method of determination.	Nitrogen as ammonia from—				
		Casein.	Dried blood.	Soy bean cake meal.	Cotton-seed meal.	Linseed meal.
		Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
2 days	Distilled directly with MgO	49.0	4.5	13.4	6.2	7.3
	HCl solution distilled with MgO	47.2	2.8	12.0	4.8	5.6
	HCl solution distilled with NaOH	44.4	4.2	9.9	4.3	6.4
		42.0	4.2	10.3	4.1	5.6
4 days	Distilled directly with MgO	52.1	14.3	27.9	12.7	16.2
	HCl solution distilled with MgO	44.8	15.0	20.5	12.3	13.1
	HCl solution distilled with NaOH	44.8	15.9	22.4	12.5	14.9
		41.2	15.0	22.6	11.6	14.7
6 days	Distilled directly with MgO	Lost	26.0	21.7	12.9	17.9
	HCl solution distilled with MgO	41.1	24.9	20.4	10.4	14.2
	HCl solution distilled with NaOH	35.5	Lost	20.2	10.4	15.9
		34.4	29.1	20.2	12.3	16.8
9 days	HCl solution distilled with MgO	25.2	19.8	13.0	11.2	14.9
	HCl solution distilled with NaOH	24.8	23.5	19.6	9.9	14.7

The different materials were converted into ammonia at greatly different rates. Casein was the most readily ammonified, the concentration of ammonia having reached a maximum at the end of two days, when about 40 per cent of the nitrogen had been converted into ammonia. After four days the ammonia content became considerably reduced. In view of the yields of ammonia found in experiments with soil (Series II) it is probable that ammonification was active for longer than two days, but then evaporation and nitrification more than equaled ammonification. The rapidity with which casein [1] was ammonified as compared with the other materials is especially interesting.

The formation of ammonia from dried blood took place slowly during the first two days, but later the yield approached that from casein. Soy bean cake meal was ammonified considerably more

[1] See Brown, Iowa Sta. Research Bul. 11; Centbl. Bakt. [etc.], 2. Abt., 39 (1913), pp. 61–73.

rapidly during the first four days than dried blood, after which time the yields decreased; while cottonseed meal and linseed meal each gave lower yields, the highest concentration of ammonia from the former being on the fourth day and from the latter on the sixth day.

Direct distillation with magnesia after two days yielded slightly more ammonia in most instances than the other methods. Later the results by the different methods were fairly concordant. With only a few exceptions, as large amounts of ammonia were obtained by distilling the hydrochloric acid extracts with magnesia as with caustic soda.[a] The above data therefore give but little indication that hydrolysis was more rapid than ammonification.

SERIES II—AMMONIFICATION IN SOIL.

This series of experiments was conducted with the fresh heavy clay soil from which the infusions were made in the previous series. One-hundred-gram portions were each thoroughly mixed with 1 gram of the nitrogenous materials and 1 gram of calcium carbonate and placed in tumblers. Sterile water was added so as to bring the moisture up to 25 per cent. After incubating at 28° C. the ammonia was determined as in the previous series. On the ninth day the nitrate was also determined in separate portions by the phenol disulphonic acid method, and was added to the average ammonia at this period in estimating the total ammonification.

Amount of ammonia formed in soil from different substances.

Period of incubation.	Method of determination.	Nitrogen as ammonia from—				
		Casein.	Dried blood.	Soy bean cake meal.	Cotton-seed meal.	Linseed meal.
		Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
2 days	Distilled directly with MgO	50.8	4.1	7.8	5.6	2.0
	HCl solutions distilled with MgO	38.1	2.2	5.6	4.8	1.1
	HCl solutions distilled with NaOH	40.0	4.2	8.1	4.2	4.2
		40.3	4.5	7.8	5.6	2.8
4 days	Distilled directly with MgO	69.4	24.1	21.8	11.5	11.2
	HCl solutions distilled with MgO	57.7	18.5	20.4	9.5	9.5
	HCl solutions distilled with NaOH	65.5	21.3	17.4	8.1	9.5
		60.5	21.6	19.9	10.1	10.6
6 days	Distilled directly with MgO	68.6	42.4	29.4	10.6	13.9
	HCl solutions distilled with MgO	59.1	40.9	26.3	9.2	10.9
	HCl solutions distilled with NaOH	56.6	33.6	28.3	10.6	10.9
		56.8	35.2	23.8	9.8	11.2
9 days	HCl solutions distilled with MgO	59.1	[b] 38.9	26.6	7.8	7.0
	HCl solutions distilled with NaOH	56.8	49.0	27.2	7.3	9.8
9 days	Nitrate N	4.4	7.4	7.0	6.3	4.6
9 days	Total ammonification	62.3	56.4	33.9	13.8	13.0
	Per cent of total N converted into NH_3.	50.2	42.4	40.9	27.1	26.0

[a] It is not surprising that practically as much ammonia was obtained by distilling the solutions with magnesia as with caustic soda, since the acid amids are decomposed by each alike, and only two other protein cleavage products, cystin and arginin, yield ammonia to caustic soda. Cystin occurs in very small amounts in most proteins.

[b] Not used in average.

The amounts of ammonia recovered from the different materials after two days and the relative rates of ammonification throughout bear similar relations to those of the previous series. In the cases of casein, dried blood, and soy bean cake meal, from which the largest yields of ammonia were obtained in the sand cultures, still greater amounts accumulated in the soil. The ammonification of cottonseed meal and linseed meal was more nearly equal at each period, being practically the same as that which took place in sand. The losses by evaporation were considerably less than from the sand, due probably to the high absorbing power of the clay. A small amount of nitrification took place, but it was not proportional to ammonification. The data for the total ammonification show a wide difference in the decomposition of the materials; 50.2 per cent of the nitrogen in casein was converted into ammonia, 42.4 per cent in dried blood, 40.9 per cent in soy bean cake meal, 27.1 per cent in cottonseed meal, and 26 per cent in linseed meal. Thus the availability of these materials as measured by ammonification varies greatly.

Direct distillation with magnesia, especially in those instances where comparatively large amounts of ammonia had accumulated, yielded considerably more ammonia than the distillation of hydrochloric-acid extracts; but, again, distillation of the latter with magnesia yielded as much ammonia as distillation with caustic soda. It would seem, therefore, that direct distillation with magnesia affords a truer measure of ammonification in clay soils than indirect distillation of hydrochloric-acid solutions. In all of the subsequent series reported in this bulletin the former method was used.

SERIES III—AMMONIFICATION OF EQUAL AMOUNTS OF NITROGEN.

In this series the nitrogenous materials were added so as to furnish equal amounts of nitrogen (132.9 milligrams). These and 1 gram of calcium carbonate were mixed with 100 grams of the same fresh soil. After bringing the moisture content to 25 per cent and incubating as before the yields of ammonia were as follows:

Amount of ammonia from equal amounts of nitrogen.

[Average of 2 samples.]

Period of incubation.	Nitrogen as ammonia from—				
	Casein, 1.072 gm.	Dried blood, 1.000 gm.	Soy bean cake meal, 1.605 gm.	Cotton-seed meal, 2.606 gm.	Linseed meal, 2.658 gm.
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
2 days	58.3	4.0	14.9	17.3	3.5
4 days	74.9	38.5	47.1	37.9	32.9
6 days	75.7	59.6	64.8	42.6	39.9
9 days	75.2	65.6	58.6	40.3	46.0
Per cent of total N converted into NH_3	56.9	49.3	48.7	32.0	34.6

The foregoing data show that when equal amounts of nitrogen were added, the amounts of ammonia formed still varied considerably. Casein was far more readily decomposed during the early stages of the action than the other materials. At the end of 2 days 58.3 milligrams of casein nitrogen had been ammonified, as contrasted with 4 milligrams in dried blood, 14.9 milligrams in soy bean cake meal, 17.3 milligrams in cottonseed meal, and 3.5 milligrams in linseed meal. Later the yields became more nearly equal and showed much less variation than when equal weights of the materials were added (see Series II). The maximum percentages of ammonia formed from the different materials, not allowing for evaporation and nitrification, the latter of which was small, ranged from 56.9 per cent from casein to 32 per cent from cottonseed meal.

SERIES IV—AMMONIFICATION IN SOIL UNDER ANAEROBIC CONDITIONS.

In order to measure the rates of ammonification under anaerobic conditions the same soil was used and sufficient sterile water added to insure complete submergence. Equal amounts of nitrogen (132.9 milligrams) and 1 gram of calcium carbonate were mixed with 100-gram portions of soil as in the preceding series.

Amount of ammonia in soil under anaerobic conditions.

[Average of 2 samples.]

Period of incubation.	Nitrogen as ammonia from—				
	Casein 1.072 gm.	Dried blood 1 gm.	Soy bean cake meal 1.606 gm.	Cotton-seed meal 2.605 gm.	Linseed meal 2.658 gm.
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
2 days	8.5	2.0	3.5	6.3	2.0
4 days	47.3	6.6	9.1	8.2	3.5
6 days	62.4	13.7	14.2	9.4	7.3
9 days	70.7	16.3	18.6	11.4	9.2
Per cent of total N converted into NH_3	53.2	12.3	14.0	8.5	6.9

The above data show that under anaerobic conditions active ammonification of casein did not begin until after two days' standing, but it then was approximately as rapid as under aerobic conditions. With dried blood, soy bean cake meal, cottonseed meal, and linseed meal ammonification took place at greatly reduced rates throughout the experimental period. The percentages of the total nitrogen converted into ammonia were as follows: Casein 53.2 per cent, dried blood 12.3 per cent, soy bean cake meal 14 per cent, cottonseed meal 8.5 per cent, and linseed meal 6.9 per cent. By comparing these data with the preceding it will be seen that anaerobic conditions greatly retarded the formation of ammonia from all the

materials except casein. As is well known, a wide range of organisms, including bacteria and fungi, have the power of splitting ammonia from organic materials. Some of these are aerobic, some anaerobic, and others facultative anaerobic. When anaerobic conditions are brought about, the formation of ammonia has usually been found to be considerably less than under aerobic conditions.

SERIES V—AMMONIFICATION WITH EQUAL AMOUNTS OF NITROGENOUS AND NONNITROGENOUS MATERIALS.

In order to make the conditions for bacterial action more nearly equal, the different materials were added so as to furnish equal amounts of nitrogen (132.9 milligrams), and the inequalities in the amounts of nonnitrogenous materials were balanced by the addition of the proper amounts of cornstarch. One gram of calcium carbonate and 100-gram portions of the above soil were used. Optimum moisture conditions were provided and the same methods employed as in the previous series.

Amount of ammonia formed, with equal amounts of nitrogenous and nonnitrogenous materials.

[Average of 2 samples.]

Period of incubation.	Nitrogen as ammonia from—				
	Casein 1.072 gm., starch 1.586 gm.	Dried blood 1gm., starch 1.658 gm.	Soy bean cake meal 1.605 gm., starch 1.053 gm.	Cottonseed meal 2.606 gm., starch 0.052 gm.	Linseed meal 2.658 gm.
	Mg.	*Mg.*	*Mg.*	*Mg.*	*Mg.*
2 days	31.0	0.3	4.4	10.3	2.4
4 days	30.9	3.3	20.1	34.8	25.8
6 days	35.8	10.4	33.5	42.6	36.2
9 days	41.8	25.2	45.4	45.2	45.3
Per cent of total N converted into NH_3	31.4	18.9	34.1	34.0	34.1

By comparing the above with Series III it will be seen that the addition of starch materially influenced the accumulation of ammonia. By adding 1.586 grams of starch the ammonification of casein was reduced practically 50 per cent throughout the nine days. The effects on the ammonification of dried blood were still more marked. At the end of two days practically no ammonia had appeared and the depressing effect was observed throughout the experimental period; after nine days only 18.9 per cent of the nitrogen added as dried blood occurred in the form of ammonia. A similar, although less marked depressing effect, was observed with soy bean cake meal, but it must be remembered that 0.605 gram less starch was added than with the dried blood. The final yields of ammonia from soy

bean cake meal, cottonseed meal, and linseed meal were almost the same, being equal to 34.1 per cent of the total nitrogen added. Thus it is shown, in common with the findings of others, that the carbon nitrogen ratio may greatly affect the accumulation of ammonia in soils.

The low yields of ammonia in the presence of carbohydrates have been attributed to stimulation of the ammonia-consuming organisms, whereby ammonia is reconverted into organic forms, and to the formation of metabolic by-products, probably of an acid nature, which exercise an inhibitory influence on ammonification; but, as shown by Lipman et al.,[1] the depressing effect of carbohydrates can not be prevented by adding calcium carbonate. It is probable that the energy derived by the ammonifying organisms themselves from the nonnitrogenous matter is of considerable importance. It is true these organisms can satisfy their energy requirements from amino compounds of various sorts, but it does not follow that a part of it could not be derived more advantageously from carbohydrates.[2] The fact that bacteria split off ammonia from nitrogenous substances, thus eliminating a portion of the nitrogen present, is in itself evidence of their demand for nonnitrogenous matter.

It should be borne in mind that the nonnitrogenous constituents of the above materials were made up of different chemical compounds including fats and carbohydrates. The exact effect of fats is not known, but different carbohydrates produce widely different effects. In general, soluble carbohydrates more markedly depress ammonification than insoluble forms.[3] The nature of nitrogenous constituents in these materials also differs considerably, and the rate at which they undergo hydrolysis, with the exception of casein, has not been extensively studied. As will be shown later, the products of acid hydrolysis vary considerably. Since hydrolysis is probably essential as preliminary to ammonification [4] any differences in the rates of hydrolysis would probably be reflected in the rates of ammonification.

SERIES VI—AMMONIFICATION WITH VARYING AMOUNTS OF CASEIN.

In the preceding series the yields of ammonia from practically the same amounts of casein varied from 50.2 per cent to 56.9 per cent of the total nitrogen added. In the following series the concentration of casein was varied and the same amounts of soil and calcium carbonate were used throughout. For the purpose of reducing evapo-

[1] New Jersey Stas. Rpt. 1911, pp. 193–212.

[2] See J. G. Lipman et al., New Jersey Stas. Rpt. 1909, pp. 166–169.

[3] See Lipman et al., New Jersey Stas. Rpt. 1911, pp. 193–212.

[4] The fact that peptone has frequently been found to ammonify more rapidly than dried blood or cottonseed meal may be due in part to its being a partially hydrolyzed substance.

ration losses, 1 gram of monomagnesium phosphate was also added, as recommended by Löhnis and Green.[1] After bringing the moisture to about 25 per cent and incubating at 28° C. for four days, the ammonia was determined as before with the following results:

Amount of ammonia formed from varying quantities of casein.

[Average of 2 samples.]

Amount of casein added.	N found as ammonia.	Per cent of total N recovered as NH_3.	Amount of casein added.	N found as ammonia.	Per cent of total N recovered as NH_3.
Gm.	*Mg.*		*Gm.*	*Mg.*	
0.2	12.0	48.4	1.5	[1] 111.7	60.1
.4	25.5	51.4	2.0	151.0	60.9
.6	43.5	58.2	2.5	192.3	62.0
.8	58.2	58.7	3.0	244.1	65.9
1.0	70.7	57.0			

[1] 1 sample only.

The percentages of total nitrogen recovered as ammonia increased as the amount of casein increased, varying from 48.4 per cent with 0.2 gram to 65.9 per cent with 3 grams (see fig. 1). Loss of ammonia by evaporation was not important, since the percentage yields were greatest where the greatest concentration of ammonia occurred. Since almost no nitrification took place in any instance, it seems reasonable to believe that, as the amount of casein added is increased, a decreasing percentage of the total nitrogen present would be consumed by the bacteria and consequently higher percentage yields of ammonia be obtained. The yield from 1 gram (57 per cent) agrees closely with that recovered in preceding series.

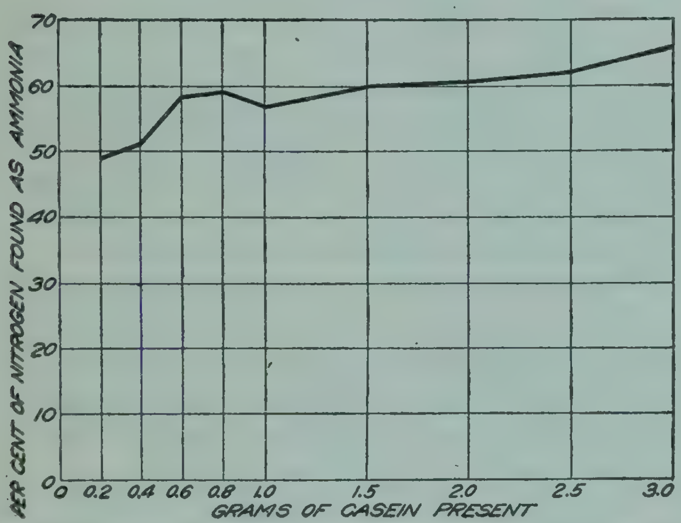

FIG. 1.—Diagram showing the ammonification of different amounts of casein.

SERIES VII—AMMONIFICATION OF CASEIN DURING DIFFERENT LENGTHS OF TIME.

This series was begun at the same time as Series VI, using the same soil. One gram each of casein, calcium carbonate, and magnesium phosphate was mixed with 100-gram portions of soil, sterile water

[1] Loc. cit.

added, and the mixture incubated as before. After four and eight days, respectively, an additional gram of casein was added in certain instances and the ammonia and nitrate determined, as shown in the following table:

Amount of nitrogen recovered from casein.

[Average of 2 samples.]

Amount of casein and period of incubation.	N recovered as NH_3.	N recovered as NO_3.	Per cent of total N converted into NH_3.
	Mg.	*Mg.*	
1 gram 4 days	72.1		57.3
1 gram 8 days	74.2		59.8
1 gram 12 days	60.2	12.5	58.6
1 gram 4 days+1 gram 4 days additional	150.9		60.8
1 gram 4 days+1 gram 8 days additional	138.9	6.6	57.1
1 gram 4 days+1 gram 4 days additional+1 gram 4 days	226.8	3.3	61.8

Practically the same amounts of ammonia were formed from a given amount of casein in four days as in longer periods. The yields from 1 gram were 57.3 per cent in four days, 59.8 per cent in eight days, and 58.6 per cent in twelve days. By adding another gram on the fourth day and allowing the action to continue four days longer 60.8 per cent of the total nitrogen was converted into ammonia. The portions treated in the same way but allowed to stand eight days longer gave 57.1 per cent yield of ammonia. Finally when 1 gram was added at the beginning and after four and eight days, respectively, 61.8 per cent of the total nitrogen was converted into ammonia.

The above data show, therefore, in common with the preceding series, that increasing percentages of the total nitrogen were converted into ammonia when increasing amounts of casein up to 3 grams were acted upon, but whether this fact was due to partial suppression of the nonammonifying organisms can not be positively stated. There is evidence, however, that under the conditions of these experiments the organisms feed on the organic nitrogen of casein rather than on the ammonia after it has been formed.

SERIES VIII—AMMONIFICATION OF CASEIN IN SILICA SAND.

The amounts of ammonia recovered from casein in the preceding experiments usually did not exceed 60 per cent of the nitrogen added, and reached a maximum point by the fourth day. In order to throw further light on this subject a series of experiments was carried out with silica sand, provision being made for absorbing whatever ammonia was volatilized. The decomposition took place in closely stoppered bottles through which a slow current of air was drawn by means of a suction pump. The current of air was first drawn through sulphuric acid to remove traces of ammonia and after passing through

the bottles was again drawn through a solution of sulphuric acid. Casein prepared by Hammarsten was employed. This was further purified by first dissolving in tenth-normal sodium hydroxid solution, then precipitating with 1 per cent acetic acid, filtering, and thoroughly washing with alcohol and ether. After drying in vacuum over sulphuric acid, the product was found to contain only 13.50 per cent nitrogen, showing that considerable impurities still remained. (Pure casein contains 15.62 per cent N.)

Five grams of the casein was mixed with 500 grams of silica sand and optimum moisture brought about by adding 50 cubic centimeters of a soil infusion prepared as in Series I. After incubating at 28° C. for one week the contents of the bottles were acidified with 1 per cent acetic acid, thoroughly shaken, filtered, and washed. The residue was then extracted with tenth-normal sodium hydroxid and the alkaline solutions acidified with 1 per cent acetic acid. No precipitate was formed and the solutions were combined with those above. Ammonia was determined in the solutions, sand residues, and the sulphuric acid by distilling with an excess of magnesia.

Total amount of ammonia formed from casein in silica sand.

Determination No.	N as NH_3 soluble in acetic acid.	N as NH_3 in the residue.	N as NH_3 volatilized.	Total yield of NH_3.	Per cent of total N converted into ammonia.
	Mg.	*Mg.*	*Mg.*	*Mg.*	
1	271.6	96.6	62.6	430.8	63.8
2	273.0	96.6	76.4	446.0	66.1
3	324.8	55.7	43.4	423.9	62.8

A slightly higher yield of ammonia was obtained than previously, the average being 64.2 per cent of the total nitrogen. Since no casein could be precipitated from sodium hydrate solutions after bacterial action, the conclusion that the entire amount of casein added had undergone hydrolysis is justified. The nature of the undetermined balance remains to be determined.

SERIES IX—AMMONIFICATION AND HYDROLYSIS OF CASEIN.

The purpose of this series was to study the relations between the rates of ammonification and hydrolysis of casein. A stock solution of casein purified as in the previous series was prepared by dissolving 15 grams in 150 cubic centimeters of tenth-normal sodium hydroxid, then diluting to 2,100 cubic centimeters. One hundred cubic centimeter portions were placed in 300 cubic centimeter Erlenmeyer flasks and 10 cubic centimeters of soil infusion added. After shaking, the flasks were loosely stoppered with cotton plugs and incubated at 28° C. The rate of hydrolysis was measured by precipitating the

unhydrolyzed casein at intervals with 1 per cent acetic acid, then making total nitrogen determinations in the precipitates as recommended by Walters.[1] Ammonia was determined in the filtrates by distilling with an excess of magnesia. In order to have a check on autohydrolysis, which is known to take place in solutions of casein, a number of the flasks were set aside without the addition of infusions and bacterial action prevented by the addition of 0.2 cubic centimeter of toluol. The casein was precipitated from these at intervals by adding 20 cubic centimeters of 1 per cent acetic acid and the nitrogen determined as above. The data showing autohydrolysis will be submitted first.

Autohydrolysis of casein in solution.

[Average of 2 samples.]

Period of incubation.	N present.	N precipitated.	N hydrolyzed.	Per cent of N hydrolyzed.
	Mg.	*Mg.*	*Mg.*	
1 hour	94.3	90.4	3.9	4.13
3 days	94.3	89.6	4.7	4.96
9 days	94.3	87.6	6.4	6.79

The above data show that in one hour's time 4.13 per cent of the nitrogen underwent autohydrolysis, and this was increased upon standing for 9 days to 6.79 per cent.

The effects of bacterial action on the ammonification and hydrolysis of casein are shown as follows:

Some results of bacterial action on casein.

[Average of 2 samples.]

Period of incubation.	N added.	N found as NH_3.	N precipitated.	Per cent of N ammonified.	Per cent of N hydrolyzed.
	Mg.	*Mg.*	*Mg.*		
1 day	94.3	0.0	90.4	0.00	4.13
3 days	94.3	.6	91.1	.64	3.39
4 days	94.3	2.5	75.9	2.65	19.51
5 days	94.3	9.7	29.6	10.28	68.61
7 days	94.3	56.1	13.8	59.53	85.36
9 days	94.3	58.7	17.6	62.25	81.32

Active ammonification set in after the fourth day and reached a practical maximum on the seventh day, when 59.53 per cent of the nitrogen had been converted into ammonia. Active hydrolysis set in after the third day and was completed by the seventh day. By this time the solutions had become quite opalescent, due to the abundance of cells of bacteria and fungi, and no precipitate was

[1] Jour. Biol. Chem., 11 (1912), pp. 267-305.

formed upon acidifying with acetic acid. The nitrogen recorded as precipitated on the seventh and ninth days, therefore, was not in the form of casein but was contained in the bacterial cells that were held up by the filter paper.

From the foregoing it is apparent that bacterial hydrolysis of casein precedes ammonification and that the former takes place considerably more rapidly than the latter.

EFFECTS OF BACTERIAL ACTION ON DIFFERENT GROUPS OF NITROGEN COMPOUNDS.

In the preceding experiments maximum ammonification usually took place in from four to six days. Of the substances tested casein was the most completely ammonified, but as stated above, usually not more than 60 per cent of the nitrogen was converted into ammonia.

The following experiments were made for the purpose of studying the effects of bacterial action on the different groups of organic nitrogen compounds. Two gram portions of the substances were mixed with 100 grams of silica sand, soil infusions added and incubated for definite periods. Then the sand mixtures were transferred to 1,000 cubic centimeter Kjeldahl flasks, 400 cubic centimeters of hydrochloric acid added, and the whole boiled under reflux condensers for 10 hours. After filtering and washing the residue with hot water, the filtrates were diluted to 1,000 cubic centimeters and aliquots used in the determination of the amid, basic, and nonbasic groups of nitrogen compounds, employing the same methods as were used in previous work on the organic nitrogen of Hawaiian soils.[1]

In every case the residues left after filtration were practically free from nitrogen, showing that all the nitrogen present went into solution, but a smaller amount was generally found than occurred in the original materials. This was probably due to the loss of ammonia by volatilization during the course of bacterial action, and to the decomposition of nitrates, and therefore, will be considered as having been converted into ammonia. It is possible, however, that some denitrification also took place. The length of time that the different materials were exposed to bacterial action varied, the purpose being to allow decomposition to continue no longer than was necessary to insure vigorous ammonification. Ammonia was determined in separate portions by direct distillation with magnesia. The original materials were also subjected to acid hydrolysis and the group determinations made as above. All determinations were made in duplicate.

The materials studied include casein, dried blood, soy bean cake meal, cottonseed meal, and linseed meal whose nitrogen contents

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[1] Hawaii Sta. Bul. 33 (1914).

have already been given. Coconut meal, containing 3.30 per cent nitrogen, globulin from cottonseed meal, containing 16.38 per cent nitrogen, and zein from maize, containing 14.03 per cent nitrogen, were also used. Neither the globulin nor the zein was entirely pure, as is shown by the nitrogen content.

CASEIN.

Nitrogen content of casein and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	3.93	....	31.96	....	....
Amid N	1.54	1.10	12.43	8.88	28.57	13.16
Basic N	2.12	0.95	17.11	7.67	59.19	11.34
Nonbasic N	8.87	6.31	71.59	50.93	28.86	75.48

The casein used was not pure. In addition to considerable ether soluble matter it probably contained small amounts of nitrogen bodies other than casein. Pure casein from cow's milk contains 10.3 per cent of the nitrogen in the form of amids and 22.4 per cent as basic nitrogen compounds, while the above material yielded 12.43 per cent as amids and only 17.11 per cent as basic compounds.

The bacterial action was allowed to continue for three days, during which time 31.96 per cent of the total nitrogen was converted into ammonia. The amid nitrogen was reduced from 12.43 per cent to 8.88 per cent of the total, basic nitrogen from 17.11 per cent to 7.67 per cent, and nonbasic nitrogen from 71.59 per cent to 50.93 per cent. Expressed in percentages of decrease we find that 28.57 per cent of the amid nitrogen, 55.19 per cent of the basic, and 28.86 per cent of the nonbasic nitrogen were ammonified. The organic nitrogen remaining at the close of the experiment was composed of 13.16 per cent amid, 11.34 per cent basic, and 75.48 per cent nonbasic nitrogen compounds. Comparing these percentages with the composition of the original casein it will be seen that the basic nitrogen compounds were decomposed more rapidly than the amids or nonbasic nitrogen compounds.

DRIED BLOOD.

Nitrogen content of dried blood and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	6.11	....	45.19	....	....
Amid N	1.23	.67	9.09	4.95	45.53	9.04
Basic N	2.52	1.09	18.64	8.06	56.75	14.71
Nonbasic N	9.77	5.65	72.26	41.76	42.17	76.25

The dried blood underwent bacterial decomposition for seven days and 45.19 per cent of the nitrogen was ammonified. The amid nitrogen decreased from 9.09 per cent to 4.95 per cent of the total nitrogen, the basic nitrogen from 18.64 per cent to 8.06 per cent, and the nonbasic nitrogen from 72.26 per cent to 41.76 per cent. Calculating the percentages of decomposition in the different groups we find that 45.53 per cent of the amid nitrogen, 56.75 per cent of the basic nitrogen, and 42.17 per cent of the nonbasic nitrogen were ammonified. These data show that the basic diamino acids were decomposed more rapidly than the other groups. The organic nitrogen remaining after the bacterial action was composed of 9.04 per cent amid, 14.71 per cent basic, and 76.25 per cent nonbasic nitrogen compounds, as compared with 9.09 per cent amid, 18.64 per cent basic, and 72.26 per cent nonbasic nitrogen in the original dried blood.

SOY BEAN CAKE MEAL.

The bacterial decomposition of this material took place for five days, with the results as given below:

Nitrogen content of soy bean cake meal and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	4.10	....	49.52	....	....
Amid N	1.24	.69	14.97	8.33	43.06	16.51
Basic N	.76	.24	9.18	2.89	67.10	5.74
Nonbasic N	6.28	3.25	75.84	39.25	48.25	77.75

The above table shows that 49.52 per cent of the total nitrogen was ammonified. The amid nitrogen decreased from 14.97 per cent to 8.33 per cent of the total, the basic diamino acids from 9.18 per cent to 2.89 per cent, and the nonbasic nitrogen from 75.84 per cent to 39.25 per cent. Expressed in percentages of decomposition it is found that 43.06 per cent of the amid nitrogen, 67.10 per cent of the basic nitrogen, and 48.25 per cent of the nonbasic nitrogen were ammonified. The organic nitrogen remaining was composed of 16.51 per cent amid, 5.74 per cent basic, and 77.75 per cent nonbasic nitrogen compounds, as compared with 14.97 per cent amid, 9.18 per cent basic, and 75.84 per cent nonbasic nitrogen in the original material.

COTTONSEED MEAL.

Cottonseed meal was exposed to bacterial action for eight days, with the results shown in the following table:

Nitrogen content of cottonseed meal and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	1.45	....	28.43	....	....
Amid N	0.78	0.59	15.29	11.57	24.37	16.15
Basic N	.96	.32	18.83	6.27	66.67	8.77
Nonbasic N	3.36	2.74	65.88	53.72	15.48	75.07

The above data show that 28.43 per cent of the total nitrogen was ammonified. The amid nitrogen decreased from 15.29 per cent to 11.57 per cent of the total, the basic nitrogen from 18.83 per cent to 6.27 per cent, and the nonbasic nitrogen from 65.88 per cent to 53.72 per cent. Expressed in percentages of decomposition it was found that 24.37 per cent of the amid nitrogen, 66.67 per cent of the basic nitrogen, and 15.48 per cent of the nonbasic nitrogen were ammonified. Thus it is found that the basic diamino acids were ammonified more rapidly than the other groups.

LINSEED MEAL.

Linseed meal was subjected to bacterial action for seven days, with the following results:

Nitrogen content of linseed meal and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	1.99	....	39.80	....	....
Amid N	0.83	.64	16.60	12.80	22.89	21.26
Basic N	.62	.38	12.40	7.60	37.09	12.62
Nonbasic N	3.55	1.99	71.00	39.80	43.66	66.11

It will be seen from the above table that 39.80 per cent of the nitrogen was ammonified. The percentages of decomposition show that 22.89 per cent of the amid nitrogen, 37.09 per cent of the basic nitrogen, and 43.66 per cent of the nonbasic nitrogen were ammonified. The organic nitrogen remaining was composed of 21.26 per cent amid, 12.62 per cent basic, and 66.11 per cent nonbasic compounds, as compared with 16.60 per cent, 12.40 per cent, and 71 per cent, respectively, in the original material. Thus it is shown, in contrast

to the materials reported above, that the nonbasic monamino acids of linseed meal were decomposed more rapidly than the nitrogen compounds of other groups.

COCONUT MEAL.

Preliminary ammonification experiments with this material indicated that the nitrogen constituents would be decomposed more slowly than in the materials reported above. After incubating one week practically no ammonia was found. Consequently the decomposition was allowed to take place for 12 days, but even then only a small amount of ammonia was formed.

Nitrogen content of coconut meal and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	0.24	....	7.27	....	....
Amid N	0.38	.37	11.52	11.21	2.67	12.09
Basic N	.52	.41	15.76	12.43	21.15	13.39
Nonbasic N	2.40	2.28	72.72	69.09	5.00	74.51

It would seem that the carbohydrates and fats protected the nitrogen bodies from bacterial decomposition, since only 7.27 per cent of the total nitrogen was found as ammonia, and the absolute amounts of nitrogen in the different groups were only slightly different from those in the original material. But the magnitude of the experimental error was relatively too great to justify positive conclusions.

The data show, however, that a higher percentage of the ammonia was derived from the basic nitrogen group than in any of the previous experiments.

GLOBULIN FROM COTTONSEED MEAL.

The globulin was prepared from cottonseed meal by extraction with a 10 per cent solution of sodium chlorid, then precipitated by saturating the solution with ammonium sulphate, redissolved in sodium chlorid solution, and dialyzed. The product was washed with alcohol and ether, and dried in vacuum over sulphuric acid, but was still impure as shown by the nitrogen content. Ammonification continued for three days.

Nitrogen content of globulin from cottonseed meal and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	4.55	....	27.77	....	....
Amid N	1.80	1.04	10.99	6.35	42.22	8.81
Basic N	3.77	1.87	23.02	11.41	50.39	15.80
Nonbasic N	10.81	8.92	65.99	54.46	17.48	75.40

The nitrogen of the original material was composed of 10.99 per cent amid, 23.02 per cent basic, and 65.99 per cent nonbasic compounds. Pure globulin from cotton seed, on the other hand, contains 10.3 per cent amid, 30.6 per cent basic, and 59.1 per cent nonbasic nitrogen. It is possible that the low percentage of basic nitrogen and the correspondingly high percentage of nonbasic nitrogen found above were due to incomplete hydrolysis, as Osborne has pointed out that some vegetable proteins require continuous boiling for 24 hours for complete hydrolysis.

The above data show that 27.77 per cent of the nitrogen was converted into ammonia, and that 42.22 per cent of the amid, 50.39 per cent of the basic, and 17.48 per cent of the nonbasic nitrogen compounds were decomposed. The organic nitrogen remaining after bacterial action was composed of 8.81 per cent amid, 15.80 per cent basic, and 75.40 per cent nonbasic compounds. Comparing the above data with that obtained with the use of cottonseed meal, it is of special interest to note that globulin, when separated from the other nitrogen and nonnitrogenous constituents of cottonseed meal, undergoes bacterial decomposition in very much the same way as do the nitrogen compounds of cottonseed meal as a whole. In each instance the basic diamino acids were decomposed more rapidly than the other groups. The amids, however, were decomposed more rapidly in the globulin than in cottonseed meal.

ZEIN FROM MAIZE.

With the exception of linseed meal the basic diamino acids of the preceding materials were decomposed more rapidly than the amids or monamino acids. The basic nitrogen in these materials varied from 9.18 per cent to 23.02 per cent of the total nitrogen. In order to study the decomposition of a substance containing still less diamino nitrogen, zein was prepared from maize by alcoholic extraction. The product was not highly purified but the analysis shows that practically all the nitrogen was in the form of zein.

Nitrogen content of zein from maize and its bacterial decomposition products.

	Per cent of original material.		Per cent of total N.		Per cent of groups decomposed.	Per cent of organic N after bacterial action.
	Before.	After.	Before.	After.		
Ammonia N	....	0.98	....	6.98	....	....
Amid N	2.75	2.21	19.60	15.75	19.64	16.93
Basic N	.43	.38	3.06	2.78	11.63	2.91
Nonbasic N	10.85	10.46	77.33	74.55	3.59	80.15

Bacterial action was allowed to continue for three days, but, as shown in the table, only small amounts of ammonia were formed. The zein as prepared was in a tough, horny condition, and was consequently difficult to pulverize, which probably accounts in part for the low yields of ammonia. The data show that the basic diamino acids were only decomposed to a slight extent; but in this case the amids were most markedly decomposed. The decreases in amid nitrogen as determined, however, may not have been entirely due to ammonification, since any amid compounds that were split off by the bacteria, but not ammonified, would have been decomposed and determined as ammonia along with that actually formed by the bacteria.

As shown above, a large portion of the nitrogen in the materials used was not ammonified, or at least did not occur at any one time as ammonia; neither was the yield of ammonia from casein in the experiments with soil materially increased by prolonging the time of decomposition beyond four days. But the cessation of ammonification was not due to the accumulation of poisonous by-products, since the second and third grams, added after the ammonification of one gram had come to a stop, were each ammonified to a slightly greater extent than the first gram. It seems probable, therefore, that a part of the organic nitrogen in the materials used is more resistant to ammonification than others. It should also be remembered that putrefactive decomposition usually takes place to some extent in the ordinary ammonification experiment, which probably results in the formation of the aromatic protein cleavage products, tyrosin, phenylalanin, and tryptophane at first; later these are decomposed into indol and skatol, rather than being immediately converted into ammonia. It seems also that a portion of the nitrogen was assimilated by the organisms present, but whether the assimilation of ammonia or organic forms took place can not be definitely stated. The latter seems the more probable. In either case it is reasonably certain that synthesis as well as decomposition plays a considerable part in the chemistry of soil organic nitrogen.

Finally the basic diamino nitrogen of organic materials is ammonified, or otherwise loses its identity as such more rapidly than the

amids and monamino acids. This phase of the chemistry of bacterial action is in harmony, therefore, with the indications given by previous study on the organic nitrogen of soils.

SUMMARY.

(1) The ammonification of casein in silica sand was much more rapid during the first two days than that of dried blood, soy bean cake meal, cottonseed meal, or linseed meal, while soy bean cake meal was second in the order of decomposition. Later loss of ammonia by evaporation reduced the concentration of ammonia, thus making it impossible to compare the rates of decomposition.

(2) During the first two days the rate of ammonification in soil was similar to that in sand, and a much higher percentage of the total nitrogen in casein was ammonified than of the other materials. On the ninth day 50.2 per cent of the casein nitrogen, 42.4 per cent in dried blood, 40.9 per cent in soy bean cake meal, 27.1 per cent in cottonseed meal, and 26 per cent in linseed meal had been ammonified.

(3) When equal amounts of nitrogen were added, casein still underwent more rapid ammonification during the first two days than the other materials, and cottonseed meal and soy bean cake meal were more completely ammonified than dried blood or linseed meal. Later the yield of ammonia from dried blood exceeded that from cottonseed meal. During the nine days of the experiment 56.9 per cent of the nitrogen in casein, 49.3 per cent in dried blood, 48.7 per cent in soy bean cake meal, 32 per cent in cottonseed meal, and 34.6 per cent in linseed meal were ammonified.

(4) Under anaerobic conditions all of the materials were ammonified very slowly during the first two days. Later the casein was converted into ammonia approximately to the same extent as under aerobic conditions, but the other materials were decomposed much less vigorously.

(5) With equal amounts of both nitrogen and nonnitrogenous matter present the final yields of ammonia from the different materials, with the exception of dried blood, agreed closely, but the initial decomposition of casein was still much more active than the other substances. The yield of ammonia from casein on the ninth day was only 31.4 per cent as compared with 56.9 per cent in the absence of starch, and the ammonification of dried blood was reduced from 49.3 per cent to 18.9 per cent. It has been suggested that the ammonifying organisms are able to utilize carbohydrates to some extent as sources of energy. If so, smaller amounts of ammonia would consequently be split off from proteins in the presence of carbohydrates. Hence the carbon-nitrogen ratio would materially affect the actual formation of ammonia in soils.

(6) When the amounts of casein were varied, other conditions remaining constant, the yields of ammonia in four days increased as the amounts of casein present increased; 48.4 per cent of the total nitrogen in 0.2 gram was ammonified, 57 per cent in 1 gram, 60.9 per cent in 2 grams, and 65.9 per cent in 3 grams. It seems probable that decreasing percentages of the total nitrogen were assimilated by the organisms present as the amounts present increased, but there are probably other factors of a chemical and biological nature involved.

(7) The yield of ammonia from casein was not materially increased by extending the incubation period beyond four days, and the decomposition of the second and third gram, added after one gram had been acted upon four and eight days, respectively, was slightly more vigorous than that of the first gram. In each instance approximately 60 per cent of the total nitrogen was found as ammonia. These facts, taken in connection with the above, indicate that the incomplete ammonification was not due to the inhibitory effect of the decomposition products, but rather that a part of the nitrogen of casein is extremely resistant to ammonification. It is also possible that a large part of the remaining nitrogen was assimilated by the bacteria.

(8) Casein when mixed with silica sand or in solution was completely hydrolyzed by the action of bacteria in seven days. In the former instance, 64.2 per cent of the nitrogen was ammonified and in the latter 59.53 per cent. In solution the rate of hydrolysis exceeded that of ammonification, but the latter was not so active during the first five days as when mixed with soil (see Series IV).

(9) The determination of the different groups of nitrogen compounds before and after bacterial action in casein, dried blood, soy bean cake meal, cottonseed meal, linseed meal, coconut meal, globulin from cottonseed meal and zein from maize shows that, with the exception of linseed meal and zein, the basic diamino acid nitrogen was converted into ammonia more rapidly than the nitrogen of other groups. With casein, soy bean cake meal, and cottonseed meal the more rapid ammonification of the basic nitrogen was especially noticeable. When this fact and the above are considered in connection with a comparison of the organic nitrogen of soils and vegetable proteins, it becomes apparent that all portions of the organic nitrogen in the different materials used as fertilizers and green manures are not equally susceptible to ammonification. It is evident, therefore, that chemical factors inherent in the nitrogen compounds themselves predetermine the availability to some degree. Further investigation, including a study of the decomposition of individual amino acids and acid amids, is being made.

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Issued August 26, 1915.

HAWAII AGRICULTURAL EXPERIMENT STATION,

J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 40.

THE SOILS OF THE HAWAIIAN ISLANDS.

BY

W. P. KELLEY,
Chemist,

AND

WM. McGEORGE

AND

ALICE R. THOMPSON,
Assistant Chemists.

UNDER THE SUPERVISION OF

STATES RELATIONS SERVICE,
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[Under the supervision of A. C. TRUE, Director of the States Relations Service, United States Department of Agriculture.]

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[1] Resigned October 27, 1914.

LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *September 29, 1914.*

SIR: I have the honor to submit herewith and recommend for publication as Bulletin No. 40 of the Hawaii Experiment Station a paper on The Soils of the Hawaiian Islands, by W. P. Kelley, chemist, and William McGeorge and Alice R. Thompson, assistant chemists. The soil investigations of the station for the past six years have greatly helped in elucidating Hawaiian soil problems. In the present bulletin the practical bearings of these scientific investigations are pointed out.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director, Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON, *Secretary of Agriculture.*

CONTENTS.

THE SOILS OF THE HAWAIIAN ISLANDS.

INTRODUCTION.

The purpose of this bulletin is to discuss briefly the general properties of the soils of the Hawaiian Islands and to point out the practical bearings of the investigations[1] that have been made on them. For about six years the writers have been investigating these soils. One phase of this work has been in the nature of a soil survey. In this connection a large number of samples have been collected and a number of unusual peculiarities and soil types have been observed. Soon after beginning this work it became apparent that the main body of Hawaiian soils had not been scientifically investigated. Considerable study had been previously devoted to the soils of Hawaii, but always with reference to special localities or industries. Maxwell's[2] discussion is based on analyses of samples drawn from the lands devoted to sugar cane and his use of the terms "uplands" and "lowlands" refers to the humid and arid, or upper and lower portions, respectively, of the sugar belt. However, only about 250,000 acres lying along the shore line, out of a total area of over 4,000,000 acres, are cultivated in this crop. The investigations upon which this bulletin is based were made principally on the upland soils above the sugar belt.

Almost the entire surface of Hawaii is characterized by a rolling topography. The elevation increases everywhere in passing inland from the sea, the grade varying in different localities. Each island contains one or more mountains or mountain ranges and usually with numerous spurs and sharp ridges projecting toward the sea. In almost every section the arable land is broken up by gulches or deep ravines, which now form natural watercourses, the beds of some of which have been worn to great depths. This has brought about the loss of a great amount of tillable land and adds greatly to the cost of farm operations. The tillable lands generally occur in comparatively narrow strips of irregular size and shape between gulches and extend from the sea toward the mountains.

It is difficult to estimate the area of arable land, only a small percentage of which has yet been brought under cultivation. The main portion is now being used for pasture in much the same way as in the great range sections of the mainland. The rainfall varies

[1] See Hawaii Sta. Buls. 26, 28, 30, 31, 33, 35, 37, and 38.

[2] Lavas and Soils of the Hawaiian Islands. Honolulu, 1898.

between wide extremes; in some localities semiarid or even arid conditions prevail, but over a large part of the uplands the rainfall is sufficient for a great variety of crops. In portions of the windward side of Maui and Hawaii, i. e., the side first reached by the northeast trade winds, the rainfall is very heavy. Until recently the main portion of the upland on account of its inadaptability to sugar was thought to be unsuited to cultivated crops. Slowly, however, it is being brought under cultivation and with the advent of a more numerous small farming class it is likely that practically all of the tillable lands of the islands will be utilized for cultivated crops. There are no valid reasons why general farming could not be practiced on these lands. The soils are rich and adapted to a wide range of crops. In the more arid sections the application of the principles of dry-land farming will doubtless insure the success of many crops. The increasing demands for land for cultivation in recent years have brought to the station many requests for information regarding the soils. A part of this information it is hoped will be supplied by this bulletin.

It should be understood from the outset that the methods of classification and mapping usually employed in soil surveys are not adapted to Hawaiian conditions and that nothing less than a systematic sampling of almost every acre will suffice to give an accurate idea of the location of all soil types. This is especially true of Oahu, where both the chemical and physical composition vary greatly in passing over short distances. For this reason no attempt to map the soil areas will be made. Furthermore, the peculiar properties of Hawaiian soils are such as to render the use of terms employed in the description of soil types elsewhere of doubtful application. In some instances the common systems of classification have been used, however, but the reader is cautioned against too strict interpretation of these terms.

The term "clay" especially requires definition. In the Tropics, where the soils have been formed from the disintegration of basaltic lava, the so-called clay is usually not composed of aluminum silicate, and its properties sometimes differ greatly from true clay. The soils of Hawaii, although usually very heavy in character and frequently containing as much as 50 per cent by weight of particles as fine as clay, are not clay soils in the true sense. They are characterized by a high content of iron and aluminum hydrates and low silica content. Such soils are designated as laterites, and recently the process leading to their formation has been designated as lateritization, in contradistinction to the term "kaolinization," used in reference to clay formation. The clay seems to be composed mainly of iron and aluminum hydrates and a double silicate of iron and alumina.

There are also some very unusual types of soil in the islands. On Oahu highly manganiferous and titaniferous soils occur, the former sometimes containing almost 10 per cent manganese oxid and the latter as high as 35 per cent titanium dioxid (TiO_2). No such soils are known to occur in any other country of the world.

ORIGIN AND FORMATION.

The soils of the Hawaiian Islands, with the exception of small areas near the sea, have been formed from the disintegration products of basaltic lava. The lava is composed mainly of pyroxenes, amphiboles, and soda-lime feldspars, with small amounts of magnetic oxid of iron. They are, therefore, highly ferruginous and basic. At the time of flow, and possibly to some extent afterwards, the vapors of burning sulphur act on the lava with the consequent formation of sulphates. The frequent occurrence of gypsum is traceable to this cause. The most important disintegrating agent is weathering. One of the first changes which takes place in the lava is that of oxidation. The iron in the original lava occurs mainly in the ferrous state, but upon exposure to the air the normal gray color quickly changes to red or yellow, due to the oxidation and subsequent hydration of the iron. Coincident with oxidation leaching takes place. The lime, magnesia, and soda to a large extent, and potash to lesser degree, are leached out by rain waters as silicates and carbonates, leaving behind a residue rich in iron and alumina, but much reduced in silica content.

The normal lavas from the main craters seem to be quite uniform in composition, while the flows from the secondary craters vary in composition, due perhaps to mixing with weathered and partially decomposed material near the surface. As oxidation proceeds, the surface of the lava crumbles away, thus allowing rain waters free access to the interior, and consequently greatly increasing the rate of solution. Another potent agent in the formation of soils is the growth and subsequent decay of plant roots. Within an incredibly short time after a lava flow plant life gains a foothold, which, aided by the solvent and oxidative effects naturally going on, soon pushes its roots into cracks and crevices. The carbonic acid given off by the roots aids in the decomposition, and the excessive heat of the tropical sun considerably hastens the solutions and oxidations going on. In general, soil formation is extremely rapid in the islands.

Much of the soil at the lower elevations has been formed by sedimentation and erosion from higher elevations. In fact there is much evidence that these processes account mainly for the location and formation of the sporadic types of manganiferous and titaniferous soils of Oahu. In many places, however, the soils are residual, with only slight transportation of soil material at most. In many sections

the disintegration has been so complete that scarcely a trace of unaltered lava can be detected in the soil.

The soils range from 6 inches to many feet in depth. After a few years of cultivation but little demarcation between the soil and the subsoil is left, except in locations of heavy rainfall. The humus content in passing downward decreases slowly, but the fertility in the drier sections is not greatly different for many feet below the surface. Where the drainage and aeration conditions are suitable, plant roots penetrate to great depths, and there is every indication that the plant food is as available several feet below as on the surface. No injurious effects, such as commonly follow the turning up of inert subsoil, are produced in the drier sections by plowing to the depth of 30 inches.

PHYSICAL PROPERTIES.

It is recognized that the physical properties of Hawaiian soils demand far more attention than usual; and it seems that purely physical factors within the control of the farmer are probably more important than the chemistry involved. The difficulties met with in the maintenance of suitable tilth, the rapidity with which the soil becomes closely compacted following rains, the lack of drainage and aeration, and the striking effects of green manuring and soil burning are all probably explainable in large part on physical grounds.

MECHANICAL CLASSIFICATION.

No attempt will be made to classify completely the soils of every section; in general, however, they may be divided into clay, silt, sandy, and humus soils. The clay type is the most abundant and in some instances contains unusually large amounts of clay, ranging as high as 50 per cent. The upland soils of Oahu, with the exception of the manganiferous and titaniferous areas, belong to the heavy clay type. The subsoils usually contain still more clay. In these sections practically no sand or gravel occurs, and the humus content is comparatively low. The soils of windward Oahu contain somewhat less clay than the above and more silt and gravel, and are consequently less difficult to till, but the subsoils contain higher percentages of clay and much less organic matter than the surface soils. The manganiferous and titaniferous soils, above referred to, are silty in character, while small areas of arable land in some localities around the coast on the leeward side of Oahu resemble adobe.

The Haiku district of Maui is composed largely of clay and clay loam soils with somewhat more humus than on Oahu. The Kula district is characterized by a light silty soil of high humus content which is several feet deep in some places. The Nahiku soils are high in humus and contain much stone and gravel. The soils of

west Maui, particularly the land of the Honolua Ranch Co., belong to the clay type.

On the island of Hawaii great diversity of soil types occur, and only the most general statements can be made at the present time. In the Olaa district, where the precipitation is very heavy, the soils contain a large amount of partially decomposed organic matter and are sandy or gravelly in texture. Along the Hamakua coast above the sugar belt a comparatively high percentage of clay occurs in some places; in others the soil has a high humus content. The soils of the Kohala district are clay loams, shading off to the west into silty loams. There is a large body of a deep, loose, silty soil, high in humus in this district that is now occupied by the Parker Ranch Co. In the Kona section the soils vary enormously. In places the virgin fern soils contain unusually high percentages of humus and, generally speaking, more or less stones and gravel.

The soils of Kauai, that have been most thoroughly investigated, were from Kapaa and the McBryde homesteads. The Kapaa lands contain high percentages of clay and are liberally supplied with humus; sometimes they resemble adobe. The McBryde homestead section is composed principally of clay loams. An insufficient number of samples have been examined from the other sections of the islands to justify any generalization. The table of mechanical analyses at the end of the bulletin will give some idea of the physical composition of representative samples from different districts.

DRAINAGE CONDITIONS.

Proper drainage is one of the greatest necessities in Hawaiian soil management. The rainfall in some sections is heavy throughout the year, and in almost all sections heavy rains sometimes occur. It is of the greatest importance that the excessive rains be able to drain away without eroding the surface into gullies or flowing over it, for in the latter event great injury will result from puddling the clay and shutting the air away from the roots of plants. Unless proper drainage be provided, suitable conditions of aeration in times of wet weather will be impossible. One of the most perplexing questions that the pineapple growers have had to contend with is that of drainage, and as yet no thoroughly satisfactory method has been devised. Generally the open-ditch system prevails. Drainage is naturally most difficult in heavy clay soils such as predominate in the pineapple sections.

The application of lime for the purpose of ameliorating the heavy clays seems to be of doubtful effect. In some instances lime fails to cause granulation such as takes place in normal clays. The clay is present in a state of such fine division as to be colloidal and has the power of imbibing large amounts of water. When wet the iron and

alumina become partially hydrated, and the soil mass swells considerably, thereby effectively closing the pores. Upon drying out contraction takes place, which results in the formation of large cracks. Thus the roots are injured and a condition provided for rapid evaporation of the soil moisture. This can be prevented only by increasing the humus and maintaining a mulch on the surface. It is evident from the above that a condition of insufficient aeration prevails in the clay soils during times of wet weather, and in fact anaerobic conditions often prevail.

Investigations on the physical properties of Hawaiian soils show that fertilizers exert considerable physical effect. Phosphates materially retard the movement of moisture in the heavy clays, while nitrate of soda produces similar effects in some of the highly organic soils. A number of fertilizing substances cause a deflocculation of the clay. It has been found, on the other hand, that heat causes the clay to become granulated and, therefore, is a means of increasing aeration and drainage.

The predominant color of Hawaiian soils is red, due to iron which is present in large amounts. Various shades of red often occur close together. There are also considerable areas of yellow soil. These colors seem to be referable to the state of hydration of the iron. The dark red color which predominates in the more arid sections is probably due to amorphous hematite and the yellow color to limonite. In the humid sections, where the humus content is not high, the color of the soil is generally lighter, due to the iron being in the ferrous form. The iron is generally so abundant and completely disseminated in the soil as to obscure the humus unless present in large amounts.

CHEMICAL CHARACTERISTICS.

Soils naturally partake to a considerable extent of the nature of the minerals from which they have been derived, and, since Hawaiian soils have been formed from basaltic lava, they are potentially basic. This does not mean, however, that in all cases the soils are free from acidity, as will be pointed out later. In general Hawaiian soils contain unusually high percentages of iron and alumina, the former sometimes exceeding 50 per cent by weight. The silica content is low as compared with mainland soils. Lime and magnesia are present in quite variable amounts, but usually more abundantly than in nonlimestone countries.

POTASH.

The potash content on the whole is rather below the average, but frequently it is relatively more soluble than usual and consequently more available. It is also more constant in different sections of the islands than any other of the so-called plant-food constituents.

PHOSPHORIC ACID.

Phosphoric acid is comparatively abundant, but there is a wide range of variation in the percentages present. The upland soils of Oahu generally, but not always, contain less phosphoric acid than any other extensive body of arable land in the islands. The soils of windward Oahu, with the exception of the lowlands devoted to rice, also usually contain small percentages of phosphoric acid. The Kula soils are rich in phosphoric acid, the Haiku soils intermediate, while in the Nahiku section of Maui the content is variable. The soils of Kohala on Hawaii are unusually rich in phosphoric acid. It must not be understood that the above statements apply universally to a given section for there is often great variation in comparatively short distances.

Notwithstanding the high percentages of phosphoric acid in many Hawaiian soils the availability is, on the whole, rather low, and phosphate fertilization is necessary in most instances except where the humus content is high. The low availability of the phosphoric acid is probably due to its being chemically combined with iron and aluminum in difficultly soluble combinations. Hawaiian soils have the power of fixing enormous amounts of soluble phosphates. Experiments have demonstrated that the red clay type of soil can fix more than 4 per cent of its weight of phosphoric acid. There is, therefore, very little danger of loss of phosphoric acid by leaching. On the other hand, it is also necessary to thoroughly mix phosphate fertilizers with the soil in order that the distribution of roots may not be too near the surface. Experiments seem to indicate that various phosphates continue to be available for a considerable time after having been applied, notwithstanding the fact that the phosphoric acid is insoluble in water. Decaying organic matter exercises a very marked effect on the availability of phosphates, and even insoluble forms may be made available by plowing under green manure.

NITROGEN.

As stated above, the humus content is high as compared with mainland soils, and consequently the nitrogen is also high, but its availability is low, due to poor aeration. The soils of Kula, Nahiku, Olaa, and parts of Kohala and Kona on Hawaii are generally very rich in nitrogen. Table II shows the percentages of humus and nitrogen in representative samples from these districts.

On account of there being a high percentage of nitrogen present, it is desirable to increase its availability whenever possible. This can best be done by increasing the aeration, thereby improving the conditions for bacterial action which decomposes the organic nitrogen into available forms. It has been found, however, that heating soil

greatly increases the ammonia content and is a means of making available a considerable portion of the nitrogen, but it should be remembered that in so doing considerable loss of nitrogen takes place through the destructive effect of the heat.

PECULIAR SOILS.

One of the peculiarities of Hawaiian soils is the unusually high content of some of the rarer elements, notably manganese and titanium, which are supposed not to be necessary for plant growth. The manganiferous soils, with relatively unimportant exceptions, are located only on Oahu between the Koolau and Waianae Mountains, but it is not possible to give an accurate estimate of the extent of this type or to trace its location in detail. In general, it may be said to occur most abundantly toward the lower levels between the mountain ranges, in pockets or level stretches that receive the drainage and wash from higher levels. This type of soil occurs most abundantly in the Waipio, Wahiawa, and Halemanu districts, but may also be found in portions of Waialua, Waimea, and in the upper part of the Oahu Sugar Co.'s land. There are also small areas of highly manganiferous soil near Haiku on Maui, Homestead on Kauai, and in the Palawai Basin of Lanai.

Sometimes the manganese areas are small, while in other places as much as 20 or more acres may occur in one body. The percentage of manganese varies greatly. A few tenths of 1 per cent occur in nearly all Hawaiian soils. The manganiferous soils, however, often contain more than 5 per cent, expressed as manganese oxid (Mn_3O_4). These soils are characterized by a dark color, sometimes almost black, due to the presence of manganese dioxid, and have a silty texture in contrast to the heavy clay character of the surrounding soils. Generally concretions composed of manganese dioxid can be found mixed with the soil and more abundantly in the subsoil. The manganese is nearly always more abundant in the soil than in the subsoil. In some places where the surface soil contains more than 4 per cent the subsoil contains less than 1 per cent. A high manganese content is quite injurious to pineapples, causing the leaves to become yellow and lowering the quality of the fruit. Some other crops are also injuriously affected, but sugar cane, sisal, cabbage, turnips, and some other crops seem to be unaffected.

As in the case of the manganiferous soils, it is not possible to locate definitely all of the highly titaniferous areas. All Hawaiian soils contain comparatively high percentages of titanium. The soils of the Kunia section, however, are unusually high in titanium, containing in some instances as much as 35 per cent titanium dioxid (TiO_2), but the titanium is relatively insoluble, and consequently the usual agricultural analysis fails to show the total amount present.

It seems that titanium is inert toward plant growth. It is extremely insoluble and occurs to some extent as small fragments of a black mineral, possibly ilmenite. Generally speaking, the titanium soils are silty, but sometimes they have a very fine texture. In a few places in the upper portion of the Wahiawa district, Opaeula and Kunia on Oahu, and near Pogue's station on Maui it occurs in the form of a blue gray layer composed of very fine particles which soil the fingers very much like charcoal. Sometimes a high percentage of ferrous iron is associated with the titanium. If phosphoric acid should become chemically combined with the titanium, the insoluble nature of this compound would render it unavailable to plants.

CORAL SAND SOILS.

These soils are of relatively small importance and are located near the sea level. Such soils, as the name indicates, have been formed mainly from grains of coral sand, which are composed chiefly of calcium carbonate. After the sand banks have been built up above sea level, organic matter and small amounts of soil gradually become incorporated with them, and certain plants soon gain a foothold, resulting in the formation of humus and later in a fairly fertile soil. An important use to which the coral beds and sand banks are being put is as a source of lime which is recommended for use where liming is needed.

LIME-MAGNESIA RATIO.

Hawaiian lava contains considerably more lime than magnesia, but frequently the opposite is the case with the soil. Generally speaking, the soils formed from black sand contain much higher percentages of magnesia than lime. Therefore, the lime-magnesia ratio is abnormal. So far as is now known, however, no injurious effects are produced on crops. Experiments carried out with the object of modifying the ratio of lime to magnesia have not indicated any practical advantage to be derived in this way. The lime is much more soluble than the magnesia, even where the magnesia content greatly exceeds that of lime.

ACIDITY OF HAWAIIAN SOILS.

Notwithstanding the highly basic character of Hawaiian soils, they generally give an acid reaction toward litmus. The acidity, as determined by the Vietch method, sometimes indicates the need of large amounts of lime. In harmony with this is the very low content of carbonate except where coral sand is present. The soils around Honolulu, for example, contain not more than 0.1 per cent carbon dioxid (CO_2), although the lime and magnesia are high. It has been supposed that the sod lands are generally acid, but it seems that the slow growth of crops is due more to the lack of aeration than the presence of actual acidity. Lime has been used to considerable

extent on the sugar lands with good effects, but in many instances negative results have been obtained by the pineapple growers. Where liming is to be practiced, coral sand is recommended.

With the exception of phosphoric acid, all the mineral elements of plant food in Hawaiian soils are soluble in water to a considerable extent, and if suitable physical conditions be maintained, and the humus content kept up, the need for mineral fertilizers will be greatly reduced. The solubility of the mineral constituents can also be considerably increased by soil heating, which probably is a factor in the more vigorous growth of crops noticed where refuse had been burned.

FERROUS IRON.

Soluble ferrous iron is considered to be toxic to plants, but the amount of water soluble ferrous iron in Hawaiian soils is extremely small, except where there is insufficient aeration. Poor drainage and an excess of water in soils prevents the circulation of air, and such conditions are favorable for the formation of soluble ferrous iron. The injurious effects on crops attending heavy rains may be due to some extent to the formation of ferrous compounds. The high iron content of Hawaiian soils is composed in part of insoluble ferrous oxid, but the imperfections in analytical methods do not permit of its accurate determination. Consequently the percentages of ferrous iron are not given in the tables of analysis.

BIOLOGICAL CONDITIONS.

The availability of nitrogen in soils depends on the activity of bacteria and fungi. There are many factors that influence their activity, one of the most important of which is the state of aeration. In general the aeration of Hawaiian soils is not sufficient for the best development of beneficial bacteria. Consequently the nitrogen does not become available fast enough for maximum growth of crops.

NITRIFICATION.

Nitrification in soils requires the free movement of air, and the more restricted the circulation of air the less actively are nitrates formed. This is strikingly illustrated by contrasting nitrification in the silty soils of Kula and the Parker ranch, where active nitrification takes place, with that of the heavy clay types common in other parts of the islands. In the rice soils nitrification is suspended and the clay soils frequently contain almost no nitrate. The inertness often observed in newly plowed sod lands is due in part to the lack of nitrification. It follows, then, that any treatment which increases soil aeration also stimulates nitrification. As pointed out above, aeration may be increased by increasing the humus content, and probably one of the most important reasons for the beneficial

effects of green manuring is that it stimulates bacterial action. It is commonly believed that the presence of carbonate of lime is essential for nitrification, through the maintenance of neutral conditions, but it seems that when other conditions are suitable, active nitrification takes place in Hawaiian soils which contain unusually small amounts of lime. The results of our experiments indicate that the iron and alumina present may partially take the place of lime in maintaining the necessary neutral condition. On the other hand, experiments show that magnesium carbonate seems to be distinctly detrimental to nitrification, while the magnesia naturally present in the soils does not seem to interfere. While nitrate is probably the most available form of nitrogen, ammonia is also available for certain crops.

AMMONIFICATION.

Ammonification is more active in Hawaiian soils than nitrification, and investigations show that aeration is not as essential to this process as it is to nitrification. Aeration, however, also stimulates ammonification. During the several months, in which new lands are usually cultivated previous to planting, ammonification and nitrification are each stimulated to a considerable extent, but in many localities only very small amounts of nitrate are found. In such instances plants seem to absorb the nitrogen most largely in the form of ammonia. In the case of aquatic plants ammonia is preferable to nitrates. Soil heating stimulates the formation of ammonia, both as a direct result of the heat on the organic nitrogen and probably indirectly, by increasing the activity of bacteria. It has also been found that the application of lime stimulates the formation of ammonia, and magnesium carbonate produces still greater stimulation. The effects of magnesium carbonate on ammonification are therefore the opposite of those on nitrification.

All Hawaiian soils seem to be abundantly supplied with bacteria, and the wide distribution and vigorous growth of a great variety of leguminous plants indicate that the tubercle-forming organisms are abundantly distributed. In fact, nodules occur on the roots of many leguminous plants in the islands. Up to the present time very little use has been made of artificial inoculation, and it is of doubtful importance.

SOIL MANAGEMENT.

TILLAGE.

A part of the high cost of tillage in Hawaii is traceable to the unusual properties of the soil. The clay when wet is extremely sticky and, even when the moisture content is low, it adheres tenaciously to the plow, thus materially increasing the draft. Frequent deep

plowing, however, is a necessity. The subsoil, upon standing, becomes closely compacted, and heavy rains and walking over the surface greatly increase this tendency. Consequently it is necessary to replow at frequent intervals. In many localities the aeration is restricted to a layer a few inches in depth near the surface and nitrification scarcely ever becomes active. Deep plowing will permit the absorption of a much larger percentage of heavy rains, thus greatly reducing erosion and storing up much larger amounts of moisture for drier seasons. Most of the soils that are cultivated in pineapples become hard and closely compacted within a few months after planting. Consequently it is necessary to plow as deeply as possible between crops.

Subsoiling has not been extensively practiced, but deep plowing should be the rule in all sections. The subsoils are not very different from the soils, except in some of the rainy sections like Olaa, and, after being acted upon for a short time by weathering influences, seem to be equally as fertile as the surface soil. In the drier sections deep plowing encourages deeper root development, thus tending to enable the crop to withstand drought. Successful soil management in Hawaii, therefore, requires deep plowing, followed by frequent shallow cultivation.

INJURIOUS EFFECT OF PUDDLING.

Great care and intelligence must always be exercised in plowing and tilling clay soils. The clay particles are extremely small and tend to settle down between the coarser grains, thus clogging the pores. However, the fine particles can be made to unite into granules by the judicious handling of the soil. In the natural state carbonic acid formed from the decomposition of vegetation and aided by evaporation causes the smaller particles to coalesce into granules, which then act as if the particles themselves were coarse. In this condition a heavy clay soil may be well aerated and fertile. On the other hand, tillage, in times of too great moisture, breaks up the granules, producing a puddled condition which is very difficult to bring back into a state of granulation.

During the early stages of the cultivation of sod lands the bacterial processes bring about a rapid decomposition of the vegetable matter, which causes the clay to become granulated. After a few years, however, the organic matter has been so completely decomposed that the clay is easily puddled under the ordinary operations of cultivation. A single cultivation of such soils when they are wet causes serious puddling. The pineapple growers in the Wahiawa district have greatly injured their lands by cultivating too soon after rains. Much of the so-called exhaustion of Hawaiian pineapple soils is traceable to wet cultivation.

ROTATION OF CROPS.

The rotation of crops is essential to a permanent upkeep of the soil. It is not necessary to enumerate the reasons for this fact. Some of them still remain in obscurity. Crop rotation is of very great importance in the proper management of Hawaiian clay soils. As stated above, the humus is considerably above the average, but the peculiarities of the clay necessitate still greater amounts. The fine particles of iron and alumina become hydrated when wet and adhere to all the soil particles. Only by the maintenance of large amounts of humus can such soils be kept in a suitable condition for plant growth.

The pineapple growers, following the lead of the sugar planters, have attempted to grow the same crop continuously, but in many cases with poor results. The reason is found in the need for humus. Crop rotation will supply this need, if a green manuring crop be plowed under. Humus is the key to successful soil management in Hawaii as is the case elsewhere. At the present time this fact is being recognized by the sugar planters as never before. Instead of burning the trash and crop residue, they should be plowed under, thereby increasing the humus content. Organic matter undergoes rapid decomposition in the Tropics, and the necessary condition of aeration hastens the decomposition. It is necessary, therefore, to plow under green manure frequently. The details of crop rotation will not be discussed in this bulletin. With the pineapple lands a green manuring crop can be grown between crops. The choice of the green manuring crop will depend on the locality. It should be a legume if possible. The single-crop system can not be permanent, and it is of doubtful economy at any time. Sooner or later it must inevitably give way to diversification.

The retention of moisture during dry weather can be greatly increased by increasing the humus content of the soil, so that sufficient moisture will be retained for the growth of crops during continued dry weather. The success of crops in the semiarid sections of Kula and the Parker ranch is due very largely to the high humus content of the soils. On one of the fields at the experiment station, where a legume has been plowed under each year for the past several years, the structure of the soil has been materially modified and the moisture-retaining power greatly increased. Similar effects can be had with any of the clay soils throughout the islands. Hawaiian clay soils require a higher percentage of moisture than is usual, due to their high hygroscopic capacity and the slow movement of moisture through the soil. Hygroscopic moisture will not sustain plant life.

EROSION AND DRAINAGE.

The amount and extent of soil erosion in Hawaii can hardly be overestimated. The heavy rains wash away enormous quantities of soil. This can be prevented by a combination of deep plowing, proper drainage, and green manuring. When the soil is compacted rain waters flow over the surface rather than being absorbed, thus washing away much soil material and cutting gullies. Where ditches are provided they should be arranged close together in the direction of the greatest fall, so as to carry away the surplus water and prevent overflow. In some places much damage has been done to crops by the overflow from inadequate ditches. The use of dynamite, for the purpose of shattering the subsoil and allowing better drainage, has been practiced with good results in some localities. The plowing under of coral sand has also been effectively used in some localities as a means of improving aeration and drainage conditions, and around Honolulu gardeners frequently mix black sand with the soil for the same purpose.

USE OF FERTILIZERS.

The table of chemical analyses at the end of the bulletin shows that, on the whole, Hawaiian soils are well supplied with phosphoric acid and nitrogen with a medium content of potash. In many localities the soil contains unusually high percentages of phosphoric acid and nitrogen. Nevertheless, heavy fertilization is generally practiced, due to the low availability of plant food. It is more rational, however, to make available the plant food already contained in the soil, if this can be done economically. The methods by which this may be accomplished have already been suggested. These consist briefly in increasing the aeration by deep plowing, thorough drainage, and the frequent plowing under of green manures, which, if carried out systematically, will materially lessen the need for commercial fertilizers.

The exact fertilizer for each crop varies in different districts. In general both nitrogen and phosphoric acid give good results. Nitrate of soda, ammonium sulphate, and organic forms of nitrogen each produce good effects, but, generally speaking, organic forms and ammonium sulphate are recommended in preference to nitrate of soda, especially during seasons of heavy rainfall. The soils have the power of absorbing large amounts of ammonium sulphate, thus preventing its being leached out, but nitrate of soda is not fixed by soils.

When the organic matter is deficient the phosphoric acid is generally of low availability and phosphate fertilizers are needed. Soluble phosphates will give best immediate returns, but if applied in conjunction with decaying organic matter, insoluble forms may be used. Pot experiments at the station, carried through several crops, indi-

cate that rock phosphate, when acted upon for a few months by decaying organic matter, becomes as available as superphosphate, but when applied without organic matter the immediate effect is negligible. From these experiments it also seems that water-soluble phosphates produce better immediate effects than reverted phosphate and bone meal. It has also been found that the availability of the phosphate already in the soil can be considerably increased by plowing under green manure, and that liming in some instances is necessary before phosphate fertilizer will give its best effects. Hawaiian soils have the power of fixing very large amounts of phosphoric acid, and, therefore, loss will not be sustained by leaching. It seems, however, that where excessive amounts have been applied some of the phosphoric acid becomes reverted into unavailable forms.

When potash fertilizer is needed the sulphate is recommended, and potash, like ammonia, is not lost by leaching if applied in reasonable amounts.

CHEMICAL AND MECHANICAL COMPOSITION OF SOME HAWAIIAN SOILS.

In the following tables are given the results of chemical and mechanical analyses of a large number of soils and subsoils taken from different parts of all of the principal islands. In Table I the results of the chemical analyses of soils and subsoils[1] are given; in Table II the humus, humus ash, and total nitrogen are stated; and in Table III the mechanical composition is shown. In general the soil represents the first foot and the subsoil the second foot taken. In most instances the material analyzed represents a composite of from two to five samples taken in the same locality. The methods employed for the chemical analysis were those of the official agricultural chemists. The classification of soils adopted in the table of mechanical composition is that of Hall.[2]

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[1] The subsoil in all cases was taken in connection with the preceding soil sample.

[2] The Soil. London, 1908, 2. ed., p. 51.

TABLE I.—*Chemical composition of Hawaiian soils.*

Soil No.	Location.	Color.	Water (H_2O).	Volatile matter.	Insoluble residue.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Titanium dioxid (TiO_2).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Nitrogen (N).
	HAWAII.															
	Kohala district.															
	Puuanahulu:		*Per ct.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
326	1,300-foot level..	Brown..	10.72	13.93	35.21	12.75	19.82	3.40	0.56	0.66	0.73	0.41	0.37	1.24	0.22	0.33
327	1,400-foot level..	...do....	13.10	14.24	32.48	12.52	20.00	2.60	.96	.46	.89	.42	.22	1.26	.49	.26
328	1,500-foot level..	Red.....	4.91	24.55	31.83	11.49	22.03	2.70	.94	.70	.71	.39	.32	.46	.21	.27
	Parker ranch, Waimea:															
474	Soil.............	Brown..	13.59	20.01	33.77	7.00	16.79	1.80	.07	3.80	.85	.72	.10	2.18	.45	.65
475	Subsoil.........	...do....	16.08	20.25	30.10	8.68	17.20	2.00	.02	3.58	1.02	.40	.22	1.34	.50	.60
470	Soil.............	...do....	12.66	19.81	38.05	8.36	11.02	1.60	.20	5.41	1.16	.47	.14	2.32	.44	.68
471	Subsoil.........	Yellow..	20.69	14.33	36.44	8.76	12.30	2.20	.13	3.00	1.49	.40	.13	.45	.37	.38
	Parker ranch, Makahalau:															
468	Soil.............	Brown..	11.52	18.92	44.06	8.80	8.93	2.00	.14	2.32	1.42	.22	.33	.86	.36	.64
469	Subsoil.........	Black...	11.00	29.14	18.44	13.72	17.78	4.03	.19	3.11	1.26	.19	.37	.63	.43	.54
74	Parker ranch, Waikii	Brown..	25.46	13.08	32.69	10.13	12.59	....	.13	2.63	1.09	.14	.34	1.02	.22	.44
75	Do.............	...do....	[1] 38.45	11.82	27.44	7.52	11.27	....	.03	1.77	1.07	.15	.32	.22	.20	.23
76	Do.............	...do....	[1] 33.85	11.79	32.17	8.36	11.25	....	.02	1.54	.87	.13	.28	.17	.18	.18
	Hamakua district.															
	Paauhau:															
472	Soil.............	Brown..	[1] 28.88	25.11	13.75	16.04	10.93	4.00	.10	.39	.52	.16	.18	.25	.32	.53
473	Subsoil.........	...do....	[1] 40.64	21.88	9.24	13.84	12.62	3.20	.08	.32	.46	.18	.15	.20	.37	.27
134	Kukalau ranch......	...do....	15.01	23.80	24.93	18.41	14.14	....	.24	.72	1.54	.82	.47	.61	.27	.77
	Hilo district.															
448	Hilo Boarding School	Yellow..	16.00	25.58	15.10	19.20	16.64	4.20	.06	.50	1.80	.15	.68	.29	.53	.49
	Olaa district.															
	Glenwood:															
216	Soil.............	Black...	9.28	23.38	38.13	12.46	10.33	....	.03	3.37	2.10	.18	.60	.23	.41	.73
217	Subsoil.........	...do....	13.51	25.46	24.63	16.06	15.27	....	.02	1.35	1.67	.10	.48	.17	1.28	.51
218	Soil.............	...do....	11.33	23.57	35.58	11.94	11.62	....	.22	2.20	2.36	.14	.41	.24	.39	.59
219	Do.............	...do....	9.46	24.61	37.84	18.56	4.23	....	.28	2.15	1.78	.28	.36	.25	.39	.74
220	Subsoil.........	...do....	14.49	26.10	22.24	17.04	16.31	....	.11	1.19	1.90	.27	.15	.18	.47	.56
221	Soil.............	...do....	7.85	21.16	41.89	13.64	8.89	....	.23	2.89	2.43	.33	.49	.21	.29	.55
428	Do.............	...do....	14.94	22.24	34.99	8.24	10.73	3.20	.20	1.91	2.24	.24	1.40	.45	.22	.74
459	Do.............	...do....	[1] 25.30	18.25	29.50	9.24	8.95	2.00	.11	2.26	2.71	.14	.23	.29	.25	.51

	Kau district.															
	Pahala, 3,000-foot level:															
497	Soil	Brown	4.83	12.24	47.39	7.28	11.73	3.80	.43	6.34	5.82	.58	1.58	.27	.52	.36
498	Subsoil	do	16.95	15.89	32.41	7.40	17.62	5.00	.36	.84	2.58	.22	.68	.17	.74	.24
	Hawaii Agricultural Co. plantation:															
499	Soil	Black	7.20	15.50	46.14	6.35	10.96	3.60	.20	4.54	4.32	.42	1.02	.40	.58	.52
500	Subsoil	Brown	15.68	16.90	32.07	7.52	18.93	5.80	.16	.66	2.22	.22	.74	.27	.46	.28
	Pahala:															
531	Soil	Yellow	9.63	14.05	39.55	13.92	16.93	....	.14	1.84	2.92	.18	.36	.36	.38	....
532	Subsoil	do	10.18	11.13	41.61	13.76	17.13	....	.19	1.84	3.66	.18	.24	.27	.42	....
533	Soil	Brown	7.33	14.00	45.16	13.76	11.88	....	.18	2.60	3.90	.24	.58	.29	.38	....
534	Subsoil	do	5.72	8.58	48.90	13.48	12.49	....	.19	5.02	4.70	.24	.92	.40	.38	....
535	Soil	Yellow	10.60	17.67	34.06	14.80	18.63	....	.18	1.44	2.38	.24	.50	.43	.34	....
536	Subsoil	do	12.23	13.79	33.84	16.56	19.09	....	.25	1.62	2.64	.12	.32	.38	.32	....
	Kona district.															
112	Keauhou, Hawaii Tobacco Co.	Brown	21.85	25.48	18.21	16.08	16.82	....	.12	.45	.84	.10	.09	.29	.41	.55
113	Do	do	16.30	28.16	21.32	16.73	13.91	....	.06	.72	.99	.14	.11	.41	.49	.28
	Honaunau:															
422	460-foot level	Black	10.71	36.50	26.43	7.44	7.76	1.40	.17	5.74	1.86	.23	.51	.96	.43	1.68
423	Subsoil	do	9.69	22.29	35.92	9.64	11.83	1.80	.18	5.80	2.23	.18	.54	.77	.48	.81
420	Lot 67, 510-foot level.	Brown	12.27	19.35	34.23	11.36	14.85	1.80	.26	2.78	2.03	.22	.28	.74	.37	.59
421	Subsoil	do	15.01	14.53	34.28	11.20	17.95	3.00	.21	2.36	1.48	.17	.23	.47	.27	.29
424	Lot 77, 680-foot level.	Black	10.34	18.69	40.86	9.32	12.85	1.80	.33	3.14	1.73	.27	.40	.55	.90	.69
425	Subsoil	do	10.50	14.70	43.02	10.08	13.77	2.20	.25	3.03	1.61	.18	.43	.59	.30	.46
418	Lot 36, 760-foot level.	do	9.87	14.36	45.48	9.00	14.19	1.98	.14	2.31	1.45	.29	.29	.97	.30	.41
419	Subsoil	do	9.43	12.26	47.09	9.84	13.97	2.00	.15	2.49	1.55	.23	.20	.98	.30	.31
	Kiilae:															
437	2,050-foot level	do	16.86	56.51	13.17	5.56	3.10	1.00	.52	2.46	.85	.15	.19	.40	.49	2.13
438	Subsoil	do	22.30	31.36	20.38	4.40	13.42	7.20	.08	.36	.53	.11	.15	.13	.30	.61
439	2,700-foot level	do	25.82	34.55	11.33	11.64	12.20	3.40	.08	.59	.63	.08	.19	.24	.33	.74
440	Do	do	[1] 42.11	29.58	13.14	4.88	6.26	3.20	.34	.80	.63	.16	.21	.20	.26	.92
	KAUAI.															
	Kona district.															
	Kekaha:															
495	Soil	Red	5.97	14.40	37.84	14.08	19.52	4.20	.24	1.60	1.16	.52	.38	.55	.34	.01
496	Subsoil	do	6.15	11.89	41.92	14.16	19.54	4.00	.20	.62	1.12	.50	.52	.36	.46	.01
	Makaweli:															
493	Soil	do	4.43	15.69	34.59	16.32	22.71	3.60	.26	.82	.64	.50	.40	.51	.46	.28
494	Subsoil	do	7.39	12.39	38.92	16.64	18.58	3.60	.16	.52	.76	.48	.42	.47	.50	.09
210	Soil	do	3.63	9.51	37.12	30.78	15.84	....	.39	.78	.51	.26	.47	.41	.30	.16

[1] Not completely air-dried.

TABLE I.—*Chemical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Color.	Water (H_2O). (Per ct.)	Volatile matter. (Per ct.)	Insoluble residue. (Per cent.)	Ferric oxid (Fe_2O_3). (Per cent.)	Alumina (Al_2O_3). (Per cent.)	Titanium dioxid (TiO_2). (Per cent.)	Manganese oxid (Mn_3O_4). (Per cent.)	Lime CaO). (Per cent.)	Magnesia (MgO). (Per cent.)	Potash (K_2O). (Per cent.)	Soda (Na_2O). (Per cent.)	Phosphoric acid (P_2O_5). (Per cent.)	Sulphur trioxid (SO_3). (Per cent.)	Nitrogen (N). (Per ct.)
	KAUAI—continued.															
	Kona district—Con.															
120	Hanapepe	Brown	5.52	16.84	27.19	24.07	24.06	0.25	0.43	0.05	0.32	0.37	0.22	0.47	0.30	0.25
119	Do	do	5.55	12.96	32.59	29.11	17.32	.50	.10	.05	.73	.51	.12	.25	.21	.25
118	Do	do	6.10	14.71	21.15	33.00	22.23	.40	.17	.05	.45	.39	.32	.26	.23	.23
117	Do	Red	6.24	18.65	17.96	32.05	22.17	.20	.12	.06	.57	.31	.48	.45	.25	.23
116	Do	do	7.25	17.41	16.50	35.32	21.28	.30	.17	.10	.34	.20	.45	.39	.22	.28
	Homestead, Kukuiolona:															
433	Soil	Brown	8.81	20.62	28.81	11.96	23.32	.60	4.14	.73	.66	.40	.46	.59	.35	.46
434	Subsoil	Red	5.24	14.23	35.29	14.72	25.54	.60	2.81	.45	.58	.18	.19	.24	.23	.12
	Kauai Fruit & Land Co.:															
209	Soil	do	6.86	24.05	25.76	32.46	15.58	....	.05	.40	.74	.16	.20	.84	.39	.25
429	Do	Brown	9.96	17.84	25.96	21.76	20.37	2.80	.08	.23	.65	.23	.30	.24	.35	.30
430	Subsoil	Red	8.61	14.91	26.41	23.92	23.40	1.60	.10	.24	.52	.22	.19	.18	.25	.16
	McBryde homestead, 1,000-foot level:															
431	Soil	do	10.30	17.30	27.51	19.84	21.06	2.40	.10	.27	.70	.13	.21	.18	.34	.27
432	Subsoil	do	8.86	13.82	32.71	17.04	24.79	1.40	.04	.27	.72	.18	.18	.33	.18	.11
207	Homestead	do	5.88	16.50	34.17	20.60	20.03	....	.18	.43	.49	.44	.20	1.01	.39	.36
	Koloa:															
373	Soil	Brown	8.77	19.58	26.08	20.04	21.96	1.20	.09	.26	.73	.42	.22	.66	.36	.29
374	Subsoil	Red	7.53	15.19	28.65	22.64	22.77	1.20	.04	.16	.54	.40	.37	.55	.31	.13
375	Soil	Brown	8.82	21.81	17.80	24.16	22.47	1.40	.01	.49	.77	.30	.29	1.05	.38	.38
376	Subsoil	Red	8.53	17.04	19.33	26.56	25.59	1.20	.02	.20	.49	.31	.33	.81	.27	.13
	Puna district.															
208	Nawiliwili, coral soil	Gray	.95	20.28	2.82	2.28	.11	....	.00	68.64	2.59	.27	.05	.48	.53	.12
	Kapaa:															
200	Soil	Brown	23.78		30.84	42.43		....	.14	.32	.68	.50	.74	.13	.44	.36
426	Do	do	10.47	18.28	24.80	22.52	19.10	3.80	.22	.15	.44	.28	.74	.19	.39	.29
427	Subsoil	Yellow	12.80	17.10	16.62	28.92	21.93	1.60	.11	.30	.59	.25	.40	.29	.34	.16
	Koolau district.															
212	Anahola	Red	16.66	10.10	37.84	19.02	24.31	....	1.39	.93	.60	.44	.29	.40	.49	.37
211	Kilauea plantation	do	9.50	18.52	19.97	36.28	13.77	....	.06	.29	.45	.26	.30	.33	.38	.31

	Halelea district.															
460	Hanalei	Brown	13.71	12.15	36.56	14.04	17.31	2.40	.08	1.08	2.31	.14	.09	.38	.23	.22
461	Do	...do	13.24	12.43	35.10	14.84	17.46	2.60	1.01	.84	2.91	.23	.09	.45	.24	.21
462	Do	...do	10.23	11.03	42.47	13.32	17.15	2.40	.02	1.07	2.06	.17	.36	.48	.31	.18
463	Do	...do	11.29	9.25	41.72	16.16	12.07	1.80	.04	.86	6.20	.15	.30	.31	.27	.16
464	Do	...do	11.83	11.45	39.83	13.56	17.92	2.60	.12	1.12	1.52	.13	.37	.45	.25	.18
465	Do	...do	11.83	10.05	40.37	13.44	17.66	2.00	.20	1.18	2.34	.12	.40	.64	.28	.13
466	Do	...do	14.50	10.12	38.81	15.56	14.53	2.20	.13	.80	3.53	.13	.25	.27	.23	.15
467	Do	...do	10.89	11.88	38.51	14.20	18.09	2.40	.12	1.04	2.71	.15	.30	.50	.28	.15
	LANAI.															
121	Beet-sugar soil	Red	5.41	17.58	33.44	18.93	19.99	.20	1.13	1.15	.45	.41	.39	.43	.26	.33
	Komoku:															
412	Soil	...do	5.88	18.64	29.26	20.00	21.13	2.40	.75	1.07	.67	.49	.22	.52	.39	.52
413	Do	...do	5.10	14.28	27.96	29.20	16.33	4.20	.40	.87	.61	.33	.11	.15	.33	.44
414	Subsoil	...do	5.00	11.44	29.68	30.88	18.40	3.20	.05	.54	.44	.25	.22	.16	.25	.20
	MAUI.															
	Hamakuapoko district.															
	Haiku:															
60	Soil	Brown	2.98	10.14	34.93	36.88	12.56	....	.07	.15	1.25	.25	.18	.20	.23	.27
62	Do	...do	4.42	16.10	34.16	21.66	21.17	....	.83	.24	.83	.48	.13	.17	.38	.30
174	Soil, 1-2 inch depth	Slate	.62	3.60	40.12	47.04	.12	3.80	.16	.54	2.12	.34	.53	.11	.72	.07
175	Subsoil, 30-inch depth.	...do	2.38	6.54	38.50	44.75	.12	3.80	.22	.46	1.68	.32	.53	.11	.74	.12
321	Maui cannery, Haiku.	Brown	4.47	13.48	32.90	30.59	13.17	3.80	.05	.44	.95	.27	.11	.30	.35	.27
322	Do	...do	4.53	13.74	25.24	34.00	16.98	3.80	.04	.33	.88	.15	.06	.56	.32	.17
323	Do	...do	3.59	10.03	33.96	35.05	12.24	3.40	.04	.26	.81	.14	.10	.28	.25	.16
324	Do	...do	16.48	....	27.29	31.62	15.78	5.00	.04	.15	.61	.15	.23	.45	.25	.20
325	Do	...do	6.80	5.67	30.74	36.86	11.34	6.60	.14	.14	.80	.20	.15	.66	.12	.11
542	Baldwin pineapple land, Haiku.	...do	5.50	13.96	30.54	19.44	13.15	5.40	.17	.21	.99			.52	.19	.27
543	Do	...do	5.53	14.62	29.28	19.44	23.27	5.20	.20	.20	.97	.17	.13	.64	.09	.31
544	Do	Yellow	4.33	13.62	28.65	25.28	21.53	5.00	.16	.09	.94	.22	.18	.19	.11	.26
545	Do	Brown	5.45	16.34	27.03	20.32	24.51	4.20	.46	.11	.91	.28	.10	.22	.22	.32
546	Do	...do	4.34	13.87	33.35	26.72	15.78	5.20	.08	.12	1.09	.23	.05	.26	.10	.28
547	Do	...do	3.12	12.20	34.54	23.80	17.72	6.20	.08	.40	1.25	.19	.13	.43	.10	.26
548	Do	...do	3.88	9.29	37.60	30.60	10.46	5.40	.10	.25	1.31	.11	.25	.36	.16	.19
549	Do	...do	3.50	9.94	32.50	33.00	10.16	7.20	.17	.13	1.41	.17	.28	.28	.16	.23
550	Do	...do	4.04	11.50	32.19	32.00	11.07	6.00	.13	.23	1.23	.20	.28	.38	.12	.27
551	Do	...do	4.21	9.84	35.03	29.16	12.53	7.60	.35	.33	1.30	.27	.22	.48	.13	.28
552	Do	Red	4.27	12.74	28.82	36.53	11.16	5.20	.10	.09	.82	.28	.22	.19	.11	.27
554	Lilikoi	...do	4.98	12.62	32.63	32.32	9.87	5.20	.02	.23	.84	.19	.31	.35	.14	.31
555	Do	...do	4.45	12.82	31.98	32.16	11.64	5.00	.03	.43	1.02	.17	.15	.30	.28	.40
556	Do	...do	5.72	16.00	25.74	32.60	13.24	5.00	.15	.24	.68	.16	.11	.22	.22	.24
557	Do	...do	4.52	14.79	26.20	32.00	14.82	4.80	.05	.27	.88	.23	.10	.29	.24	.34
558	Do	Brown	5.41	14.70	26.20	26.32	19.23	5.20	.06	.33	.85	.39	.12	.38	.25	.30

TABLE I.—*Chemical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Color.	Water (H_2O).	Volatile matter.	Insoluble residue.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Titanium dioxid (TiO_2).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Nitrogen (N).
	MAUI—continued.															
	Hamakuapoko district—Continued.		*Per ct.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
559	Lilikoi	Brown	6.27	17.91	22.97	27.92	17.50	5.20	0.39	0.31	1.14	0.26	0.06	0.32	0.17	0.30
560	Do	do	4.20	12.63	31.44	33.48	10.15	5.60	.13	.27	.79	.23	.17	.32	.12	.30
561	Do	do	4.67	14.00	28.98	29.84	15.46	4.60	.11	.39	.88	.23	.26	.34	.31	.31
562	Do	do	4.59	14.65	28.68	33.16	11.65	5.20	.22	.29	.95	.23	.30	.49	.21	.38
563	Do	do	4.36	15.77	25.90	30.56	14.95	5.60	.17	.20	.74	.28	.28	.48	.25	.31
564	Do	do	5.18	13.26	30.88	31.40	11.25	5.40	.11	.14	.87	.24	.27	.38	.20	.32
565	Do	do	4.60	12.74	31.28	28.20	15.68	4.80	.13	.09	.84	.30	.23	.33	.24	.27
	Koolau district.															
69	Nahiku	Brown	12.57	39.86	18.48	15.40	10.95	....	.09	.86	1.16	.18	.32	.22	.56	1.32
202	Do	do	19.96	17.56	22.45	17.22	18.96	....	.08	.87	2.16	.14	.25	.52	.42	.37
203	Do	do	19.12	25.10	17.88	18.48	17.29	....	.10	.32	.79	.24	.30	.55	.67	.66
204	Do	do	13.44	18.02	21.98	33.48	11.51	....	.06	.21	.76	.21	.19	.29	.47	.24
205	Do	do	16.44	19.02	17.98	18.56	22.70	....	.01	.81	2.94	.20	.26	.40	.75	.24
206	Do	do	16.27	22.58	29.78	19.74	9.03	....	.08	.45	.81	.19	.16	.45	.67	.65
370	Koolau forest	Gray	5.04	23.58	49.38	8.68	8.87	3.60	.02	.29	1.04	.39	.43	.05	.23	.58
371	Do	do	3.04	10.34	73.01	6.76	3.29	2.40	.02	.29	.74	.49	.33	.05	.21	.35
	Kaupo district.															
	Catholic Church:															
523	Soil	Brown	9.26	24.99	30.45	15.24	11.78	....	.17	2.92	3.44	.88	.24	.73	.80	....
524	Subsoil	do	10.52	22.21	28.52	16.52	14.27	....	.23	2.62	3.12	.56	.52	.71	.88	....
	Omsted place:															
525	Soil	do	9.40	19.87	27.12	20.04	19.65	....	.13	.72	1.00	.44	.46	.75	.78	....
526	Subsoil	do	9.73	17.19	29.63	20.04	20.18	....	.15	.70	1.04	.58	.58	.70	.70	....
527	Soil	do	9.68	20.66	27.47	24.52	15.02	....	.04	.46	.90	.56	.32	.40	1.00	....
528	Subsoil	do	10.82	19.16	26.90	24.24	16.32	....	.10	.18	.74	.80	.04	.26	.80	....
529	Popoiki	do	9.24	23.00	30.90	16.52	....	....	.43	1.94	2.32	.70	.58	.97	.84	....
	Kula district.															
	Alexander field:															
105	Soil	Brown	4.81	11.32	35.19	31.68	15.40	....	.12	.07	.84	.23	.19	.36	.29	.27
109	Subsoil	do	11.38	13.49	25.56	26.86	20.98	....	.14	.08	.35	.28	.12	.54	.82	.09
106	Soil	do	5.17	11.78	31.63	33.43	15.79	....	.17	.11	.85	.21	.15	.50	.21	.25
108	Subsoil	do	8.86	15.10	22.93	27.74	22.95	....	.14	.06	.63	.25	.17	.79	.75	.11

	Dowdle field:														
107	Soil	do	3.82	9.51	34.52	36.56	13.65	....	.23	.05	.88	.16	.07	.36	.22	.22
110	Subsoil	do	11.12	12.95	25.58	32.01	16.36	....	.23	.09	.50	.21	.13	.78	.32	.12
	Ulupalokua:															
377	Soil	do	12.33	13.69	32.73	12.88	17.17	2.40	.20	3.30	2.65	.38	.57	.71	.26	.31
378	Subsoil	do	15.29	14.21	30.40	13.68	17.05	2.60	.29	2.69	3.38	.28	.66	.67	.25	.27
	Cromwell ranch:															
379	Soil	do	12.64	25.30	18.88	13.76	23.44	3.20	.34	.90	1.10	.20	.36	.73	.33	.52
380	Subsoil	do	18.18	22.71	16.58	13.76	23.26	3.60	.17	.55	.97	.17	.37	.65	.28	.35
	Kamaole Church:															
381	Soil	do	11.29	20.40	26.39	14.24	19.57	3.00	.24	1.87	1.82	.25	.37	.55	.30	.49
382	Subsoil	do	13.73	17.45	30.30	12.52	18.36	2.60	.30	2.59	1.73	.19	.46	.49	.31	.38
	Kamaole.															
383	Soil	Black	10.26	31.17	28.42	9.52	10.73	1.60	.84	4.44	2.03	.28	.70	.81	.50	1.29
384	Subsoil	do	12.89	32.14	24.47	10.20	11.62	1.40	.47	4.57	1.83	.22	.51	.70	.62	1.38
	Waiakoa store:															
385	Soil	do	9.56	19.03	27.02	13.96	21.06	3.40	.41	2.46	1.82	.34	.45	.74	.38	.45
386	Subsoil	Brown	10.71	19.86	26.80	13.88	21.63	3.20	1.48	2.55	1.84	.41	.45	.79	.32	.45
	Ulupalakua:															
387	Soil	Black	2.14	7.11	43.77	11.08	14.39	2.20	.28	9.80	5.78	1.03	2.38	.48	.32	.22
	Kaanapali district.															
	Honolua:															
361	450-foot level	Red	10.03	12.72	40.05	14.56	18.34	1.80	.72	.54	.59	.34	.31	.40	.53	.30
362	Subsoil	do	10.19	10.30	41.07	12.88	22.32	1.60	.24	.44	.46	.31	.27	.32	.46	.12
363	650-foot level	Brown	8.35	13.26	38.61	15.36	20.10	2.40	.59	.46	.72	.23	.25	.32	.49	.29
364	Subsoil	do	8.20	12.07	39.63	15.64	21.31	2.00	.34	.32	.52	.22	.25	.27	.36	.14
365	850-foot level	Red	8.79	14.02	32.80	27.08	11.76	4.00	.32	.30	.59	.23	.24	.26	.38	.36
366	Subsoil	do	10.82	14.35	26.66	25.96	17.77	3.20	.04	.30	.39	.20	.23	.31	.43	.15
	MOLOKAI.															
	Pukoo district.															
91	Soil	Red	7.68	12.10	....	18.83	22.29	....	.20	.46	.71	....	....	.37	.20	.15
92	Subsoil	do	8.18	11.98	....	17.29	24.64	....	.18	.25	.80	....	....	.33	.14	.14
93	Soil	Brown	5.91	13.92	....	19.97	26.64	....	.21	.20	.69	....	....	.46	.18	.16
94	Subsoil	do	6.06	14.33	....	20.85	25.01	....	.04	.16	.76	....	....	.43	.21	.14
95	Soil	Red	11.53	18.38	....	20.34	19.46	....	.27	.24	.76	....	....	.32	.20	.22
	Molokai ranch.															
222	Near ranch house	Red	4.18	12.56	38.56	21.12	20.93	....	.57	.69	.50	.46	.16	.51	.26	....
	Naiwa district.															
	1,500-foot level:															
349	Soil	Red	4.39	9.90	38.73	32.36	8.61	4.60	.11	.34	.87	.23	.20	.37	.15	.24
350	Subsoil	do	8.68	13.56	26.81	34.86	11.73	2.80	.02	.20	.52	.31	.23	.46	.16	.19

TABLE I.—*Chemical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Color.	Water (H_2O).	Volatile matter.	Insoluble residue.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Titanium dioxid (TiO_2).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Nitrogen (N).
	MOLOKAI—continued.															
	Naiwa district—Con.															
	1,050-foot level:		*Per ct.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
351	Soil	Red	3.94	7.94	30.65	38.16	11.31	5.00	0.02	0.41	0.76	0.39	0.40	0.87	0.28	0.20
352	Subsoil	do	6.63	11.21	28.64	31.90	16.21	3.70	.02	.28	.56	.39	.50	.62	.09	.18
	860-foot level:															
353	Soil	do	6.18	12.84	34.67	15.64	26.15	2.40	.09	.41	.94	.29	.30	.59	.05	.18
354	Subsoil	do	5.67	12.34	36.42	15.20	24.87	3.20	.38	.58	.70	.31	.28	.69	.33	.13
	600-foot level:															
355	Soil	do	4.80	12.17	37.75	17.92	23.10	2.20	.90	.54	.56	.30	.26	.38	.40	.12
356	Subsoil	do	5.24	11.50	37.27	17.25	23.90	2.40	.74	.45	.58	.34	.35	.47	.36	.10
	380-foot level:															
357	Soil	do	4.36	12.12	38.60	15.56	24.51	3.00	.14	.28	.42	.15	.26	.40	.29	.08
358	Subsoil	do	8.63	7.16	39.76	13.32	28.14	2.40	.05	.21	.52	.20	.43	.30	.31	.08
	30-foot level:															
359	Soil	do	5.74	13.12	38.87	15.36	21.46	2.80	.16	.59	.84	.22	.23	.37	.49	.25
360	Subsoil	do	6.15	13.75	40.49	13.76	21.38	2.00	.20	.88	1.01	.29	.52	.62	.34	.19
	OAHU.															
	Kona district.															
	Waikiki:															
71	Soil	Brown	8.75	5.76	37.21	19.60	13.60		.36	2.19	12.06	.48	.82	.66	.19	.16
292	Do	do	7.65	8.42	38.49	16.63	12.85	2.00	.24	1.84	8.71	.39	1.36	.57	.08	.12
293	Subsoil	do	12.72	8.67	33.88	18.56	11.39	2.31	.18	2.17	8.51	.41	1.19	.62	.10	.14
122	Experiment station	do	7.36	11.55	35.37	35.40			.42	.82	6.24	1.32	.72	.35	1.30	.21
251	Experiment station, field B 1.	Red	9.66	10.08	32.41	26.80	14.01		.26	1.22	4.23	1.30	.12	.68	.25	.15
	Experiment station, field B 2:															
288	Soil	do	8.29	12.10	36.87	15.90	13.42	2.22	.44	1.10	7.94	.97	.76	.34	.08	.21
289	Subsoil	do	10.36	11.70	36.96	15.12	15.20	1.92	.23	.80	5.86	.66	.50	.28	.07	.15
	Experiment station, field D:															
290	Soil	Black	8.44	15.80	40.02	16.41	14.11	1.50	.30	.77	1.30	.17	.42	.27	.10	.19
291	Subsoil	do	9.33	12.77	41.21	15.89	15.39	1.25	.18	.67	1.41	.17	.40	.20	.09	.13

	Kalihi:														
332	Soil	Brown	11.39	12.38	39.56	16.66	15.13	2.00	.28	.86	.83	.22	.41	.28	.03	.16
333	Subsoil	do	12.65	11.81	40.05	16.14	15.21	1.90	.26	.76	.51	.23	.31	.23	.09	.13
334	Soil	do	8.81	12.53	41.00	16.03	17.82	1.40	.12	.74	.90	.25	.31	.41	.21	.21
405	Do	do	8.02	12.50	39.12	15.24	20.54	2.40	.15	.86	.99	.20	.48	.44	.33	.20
406	Do	do	10.34	17.73	37.31	10.92	20.20	1.80	.06	.48	.67	.20	.48	.48	.30	.41
408	Experiment station, Tantalus.	Black	11.35	18.28	22.72	19.24	17.29	3.60	.14	.42	4.94	.34	.18	1.13	.28	.45
537	Alewa heights	do	9.70	13.48	39.24	21.16	14.95	......	.28	.66	1.10	.22	.40	.21	.40	......
	Ewa district.															
63	Puuloa, Honolulu plantation.	Brown	11.07	10.34	38.14	12.04	21.63	2.20	.32	.54	2.58	.32	.46	.35	.38	......
64	Do	do	10.36	10.62	36.62	16.32	19.55	2.30	.44	.52	2.24	.34	.58	.42	.30	......
68	Do	do	10.41	10.54	36.42	17.76	18.70	2.20	.62	.50	2.22	.48	.98	.37	.28	......
	Waipio district.															
213	Robinson	Red	5.51	14.31	36.44	18.16	22.71	......	.19	.69	.55	.30	.43	.42	.42	.28
46	Do	do	7.20	19.18	30.75	16.00	22.05	......	3.05	.62	.36	.58	.24	.21	.76	.44
	Pearl City Fruit Co.:															
27	Soil	Black	14.74	11.95	35.88	18.80	13.65	......	3.53	.16	.29	.55	.27	.11	.31	.22
28	Subsoil	do	15.74	9.95	36.04	18.00	16.44	......	3.02	.18	.23	.55	.31	.09	.26	.16
29	Soil	Red	14.26	13.17	37.76	16.40	15.83	......	1.13	.28	.22	.55	.28	.10	.39	.25
30	Subsoil	do	15.12	9.99	38.93	17.12	17.09	......	.43	.14	.38	.62	.20	.06	.23	.17
31	Soil	do	16.70	14.35	34.75	19.40	13.34	......	.19	.19	.30	.44	.17	.07	.38	.24
32	Subsoil	do	21.25	12.88	29.34	19.00	16.42	......	.31	.12	.23	.45	.29	.09	.26	.16
114	Hawaiian Pineapple Co.	do	5.15	15.75	40.66	14.99	19.71	.03	2.40	.10	.47	.45	.22	.24	.23	.30
416	Do	do	6.17	17.73	36.09	13.20	20.39	1.60	3.84	.33	.44	.39	.59	.20	.35	.36
417	Do	do	16.26	17.53	30.92	11.24	19.38	1.40	2.85	.21	.36	.45	.36	.24	.43	.38
435	Makua	do	4.31	12.89	39.72	16.08	22.68	2.40	.38	.40	.57	.55	.26	.34	.24	.16
436	Do	do	5.39	14.38	35.40	16.20	25.13	2.40	.14	.54	.56	.22	.24	.19	.23	.21
	Wahiawa district.															
	Hawaiian Pineapple Co.:															
5	Soil	Red	3.80	13.20	42.13	25.12	10.41	3.40	.26	.44	.39	.60	.19	.12	.08	.24
6	Subsoil	do	4.13	13.55	37.26	31.20	10.01	2.57	.18	.44	.34	.70	.28	.15	.02	.21
7	Soil	do	3.98	13.65	39.26	34.30	3.43	3.68	.21	.50	.36	.49	.20	.06	.08	.32
8	Subsoil	do	4.44	13.37	37.50	31.80	8.28	2.62	.05	.63	.36	.57	.30	.07	.06	.24
9	Soil	Black	5.36	16.78	31.67	18.60	14.67	.68	9.21	1.32	.52	.79	.38	.20	.15	.18
10	Subsoil	do	4.73	13.77	34.35	20.50	15.00	1.04	8.35	.82	.41	.70	.40	.15	.08	.22
11	Soil	do	4.59	18.81	37.23	17.40	14.69	3.90	4.58	.61	.39	.74	.34	.35	.22	.44
12	Subsoil	do	3.53	13.24	41.10	19.80	16.27	.56	3.38	.58	.37	.78	.42	.12	.04	.18
	Waikakalaua:															
13	Soil	Red	3.99	15.34	44.66	23.40	8.79	2.12	.32	.31	.39	.48	.30	.08	.10	.37
14	Subsoil	do	2.43	12.85	45.24	23.80	11.73	2.00	.34	.30	.43	.55	.12	.12	.11	.24

TABLE I.—*Chemical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Color.	Water (H_2O).	Volatile matter.	Insoluble residue.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Titanium dioxid (TiO_2).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Nitrogen (N).
	OAHU—continued.															
	Wahiawa district—Continued.															
	Hawaiian Pineapple Co.:		*Per ct.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
96	Soil	Red	12.25	15.33	....	18.21	22.58	....	0.47	0.24	0.56	....	....	0.11	0.14	0.28
97	Do	do	7.53	13.22	41.99	19.27	16.86	....	.15	.30	.30	0.49	0.12	.17	.16	.23
98	Do	do	6.72	12.19	43.45	19.80	16.35	....	.11	.57	.22	.48	.16	.17	.14	.23
99	Do	do	11.39	13.32	30.75	27.50	16.75	....	.14	.09	.28	.44	.25	.14	.21	.24
101	Do	do	9.04	11.85	36.94	25.64	15.43	....	.09	.15	.25	.36	.19	.18	.17	.22
102	Do	do	7.33	13.62	37.01	27.10	13.71	....	.20	.11	.40	.42	.35	.18	.22	.25
103	Do	do	10.21	13.70	32.51	23.53	18.27	....	.11	.04	.21	.35	.37	.09	.18	.21
104	Do	do	7.87	11.13	39.03	21.74	20.03	....	.14	.05	.21	.42	.15	.14	.19	.19
100	Subsoil	do	13.58	13.38	25.02	23.10	23.76	....	.12	.18	.13	.26	.43	.21	.17	.17
19	Thomas Pineapple Co.	do	8.03	12.82	40.46	25.70	10.95	0.26	.14	.22	.39	.54	.27	.02	.10	.26
21	Do	do	10.43	16.00	35.03	22.40	13.21	.21	.82	.26	.31	.68	.30	.08	.15	.30
	Hawaiian Preserving Co.:															
15	Soil	Black	7.82	15.38	31.15	24.00	14.58	.19	3.70	.46	.48	.91	.19	.32	.15	.32
16	Subsoil	do	9.16	11.75	31.37	24.40	17.24	1.44	2.21	.34	.38	.97	.35	.19	.04	.18
17	Soil	do	8.33	14.97	31.96	24.20	13.61	1.42	3.58	.34	.38	.97	.27	.16	.12	.28
517	Do	Red	3.54	13.71	41.99	21.76	17.23	....	.12	.36	.32	.54	.23	.13	.58	....
518	Subsoil	do	3.97	13.56	41.53	21.48	18.21	....	.04	.20	.24	.66	.46	.16	.52	....
130	Kunia	do	7.95	16.22	30.76	20.50	21.02	....	1.18	.39	.55	.34	.23	.57	.37	.30
133	Mountain gap, Leilehua.	Gray	1.49	4.09	43.39	42.96	2.95	4.00	.03	.26	.66	.42	1.34	.09	.36	.05
72	Do	do	.82	1.34	65.90	26.75	2.24	2.16	.05	.12	1.00	.30	.96	.05	.52	....
388	Government land, Leilehua.	Red	5.53	18.07	27.04	21.24	22.63	2.60	1.28	1.19	.51	.36	.14	.32	.35	.42
389	Do	do	2.86	18.43	29.51	22.76	20.71	2.80	1.24	.47	.53	.38	.09	.37	.29	.40
390	Do	do	6.39	14.18	31.09	23.20	19.40	3.60	.73	.47	.56	.32	.14	.18	.27	.36
391	Do	do	7.10	18.12	30.52	13.28	26.25	1.40	.48	.61	.47	.44	.18	.24	.27	.34
392	Do	do	5.51	19.00	29.64	15.72	24.78	1.80	2.26	.52	.50	.40	.21	.28	.31	.35
393	Do	do	9.01	18.35	28.57	11.60	26.01	1.20	4.04	.50	.53	.46	.15	.32	.24	.36
394	Do	do	3.17	7.72	26.82	39.00	13.29	9.00	.06	.33	1.01	.15	.03	.04	.19	.20
395	Do	do	3.01	5.42	37.80	35.80	9.73	6.60	.06	.73	.86	.15	.14	.17	.15	.15
396	Water tank, Leilehua.	Black	5.08	8.47	35.39	33.64	10.04	5.20	.01	.40	.59	.15	.06	.41	.20	.22
397	Dowsett House	Red	7.47	13.40	30.72	19.32	21.76	3.00	1.86	.35	.59	.37	.15	.59	.26	.20
398	Leilehua tract	Brown	6.89	18.88	29.22	15.16	19.55	2.20	6.42	.42	.61	.37	.14	.36	.30	.42
399	Do	Red	5.33	13.03	37.19	20.68	18.40	4.00	.04	.61	.63	.27	.18	.22	.25	.26

	Waialua district.														
140	Mokuleia	Brown	6.84	14.88	35.67	17.67	22.51	....	.39	.52	.41	.42	.27	.87	.15	.31
141	Do	do	8.39	12.74	39.32	17.16	20.15	....	.33	.42	.56	.41	.20	.56	.10	.41
142	Do	do	7.21	13.48	43.25	14.18	18.09	....	.27	1.38	1.52	.52	.39	.32	.08	.36
143	Do	do	7.29	11.45	45.78	14.33	17.88	....	.25	1.22	1.54	.20	.29	.15	.03	.27
331	Helemano	Red	7.49	18.69	35.21	14.84	18.20	1.40	3.26	.58	.48	.59	.05	.24	.70	.40
115	Do	do	5.66	12.17	38.22	27.89	13.86	.50	.10	.05	.80	.34	.32	.14	.17	.31
145	Opaeula Ridge	do	8.06	12.49	39.38	26.10	11.91	....	.06	.36	1.12	.32	.43	.17	.52	.31
148	Do	do	12.50	10.81	35.62	26.37	13.33	....	.07	.26	.74	.38	.13	.27	.54	.17
149	Do	do	16.66	10.45	34.50	27.30	9.79	....	.07	.24	.80	.38	.11	.19	.68	.21
152	Do	do	14.04	15.28	29.73	14.84	20.73	....	2.89	.26	.64	.42	.30	.29	.58	.32
155	Do	do	12.07	13.78	33.57	28.74	11.18	....	.10	.18	.58	.36	.30	.25	.58	.24
164	Do	Gray	1.22	3.56	48.17	37.47	3.05	1.72	.10	.12	1.22	.48	1.46	.08	.44	....
165	Do	do	.25	3.02	50.96	37.97	2.73	2.10	.06	.30	1.54	.42	1.46	.04	.34	.10
178	Waimea Ridge	Red	14.21	14.50	....	14.58	17.35	....	3.00	.50	.66	.45	.24	.43	.76	.36
186	Do	do	6.90	13.23	....	20.86	17.30	....	2.24	.74	.68	.40	.24	.16	.74	....
187	Do	do	5.58	11.52	....	33.16	11.55	....	.10	.08	.52	.37	.24	.15	.80	....
	Pupukea:															
49	Soil	do	15.51	11.49	35.79	17.20	17.21	....	.99	.20	.39	.55	.38	.08	.20	.23
50	Subsoil	do	16.04	11.19	33.43	21.72	16.31	....	.30	.10	.37	.40	.17	.08	.35	.11
51	Soil	Black	16.20	12.81	32.20	17.10	16.36	....	3.62	.20	.53	.69	.28	.09	.24	.20
52	Subsoil	do	14.90	10.59	33.82	21.60	13.73	....	3.61	.22	.42	.65	.39	.12	.24	.11
489	Pupukea, sea level	Red	5.30	14.72	36.81	18.48	21.96	2.20	.10	.48	.65	.40	.12	.31	.33	.27
490	Do	do	5.42	14.10	34.95	18.76	22.15	2.20	.34	.78	.72	.27	.16	.37	.34	.23
	Koolauloa district.															
	Koluanui:															
347	Soil	Black	9.07	31.48	34.46	6.42	13.10	2.08	.29	2.00	.72	.11	.28	.17	.30	1.13
348	Subsoil	do	13.16	40.53	24.10	5.60	10.80	1.65	.30	2.40	.68	.08	.28	.11	.70	1.25
	Koolaupoko district.															
	Waiahole:															
345	Soil	do	8.76	12.13	46.11	15.76	13.65	1.50	.38	1.10	.99	.08	.22	.19	.18	.19
346	Subsoil	do	8.78	13.39	44.04	14.78	13.97	1.48	.41	1.49	1.41	.07	.26	.21	.12	.18
25	Kohaluu	do	7.59	18.34	29.70	20.40	22.84	....	.02	.15	.70	.16	.23	.12	.29	.32
	Heeia:															
319	Soil	do	11.22	17.69	26.40	23.95	16.52	3.10	.02	.66	.62	.27	.03	.51	.31	.31
320	Subsoil	do	19.49	13.85	23.82	22.67	15.89	2.80	.04	.58	.49	.23	.12	.44	.28	.21
	Near wireless station, Heeia:															
304	Soil	do	10.34	13.80	32.59	17.95	21.04	2.90	.05	.90	.68	.25	.30	.49	.10	.24
305	Subsoil	do	10.26	13.92	32.73	17.87	21.90	2.50	.04	.87	.80	.25	.19	.52	.12	.24
302	Soil	Red	11.74	20.95	16.59	27.52	15.77	5.00	.28	.39	1.16	.28	.08	.90	.17	.53
303	Subsoil	Brown	9.49	14.86	30.47	20.26	21.23	2.60	.08	.53	.62	.23	.25	.49	.08	.20
131	Lilipuna	Red	16.94	15.82	35.30	14.88	15.16	....	.45	.29	.51	.51	.35	.38	.31	.31
508	Do	Brown	4.96	14.02	42.81	14.96	19.71	2.60	.17	.20	.58	.40	.28	.25	.34	.02
509	Do	Red	3.41	14.02	46.33	12.80	19.38	2.60	.26	.20	.60	.40	.38	.30	.34	.02

TABLE I.—*Chemical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Color.	Water (H_2O).	Volatile matter.	Insoluble residue.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Titanium dioxid (TiO_2).	Manganese oxid (Mn_3O_4).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Nitrogen (N).
	OAHU—continued.															
	Koolaupoko district—Continued.															
			Per ct.	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
194	Kaneohe, Hawaiian Pineapple Co.	Red	15.03	16.52	20.39	29.59	15.05	....	0.30	0.18	0.80	0.94	0.70	0.54	0.28	0.29
195	Do	do	11.42	15.44	31.24	22.12	16.70	....	.14	.32	.60	.56	.70	.72	.24	.30
196	Do	Black	15.02	14.27	25.80	25.52	15.81	....	.24	.68	.76	.52	.42	.71	.26	.28
197	Do	Red	9.83	15.69	37.88	18.48	15.34	....	.03	.26	.88	.54	.74	.45	.30	.32
198	Do	Black	12.21	14.91	27.17	26.62	16.65	....	.21	.22	.66	.64	.66	.41	.28	.28
	Kaneohe, near Pali:															
300	Soil	Brown	7.50	12.61	27.65	34.92	10.95	3.70	.10	.48	1.49	.24	.19	.90	.13	.35
301	Subsoil	do	9.26	10.35	26.67	35.08	13.22	3.30	.09	.28	1.10	.33	.45	.76	.08	.21
	Kaneohe, Koelings:															
306	Soil	Black	8.12	15.40	32.67	16.47	23.28	3.10	.03	.78	.66	.31	.18	.52	.10	.32
307	Subsoil	Red	10.93	17.05	16.63	26.01	22.99	4.00	.02	.44	.91	.23	.18	.98	.14	.28
	Kaneohe, Mauka road:															
308	Soil	do	9.62	18.32	20.35	20.04	26.09	2.70	.04	.64	1.01	.16	.40	.87	.25	.31
309	Subsoil	do	13.08	16.12	21.06	20.96	22.35	2.80	.6	1.11	1.50	.08	.14	.90	.38	.29
310	Soil	do	14.65	16.44	20.59	23.90	20.36	3.00	.03	.41	.37	.16	.56	.28	.18	.22
311	Subsoil	do	18.64	15.46	20.72	21.20	19.43	3.50	.02	.22	.43	.11	.31	.32	.21	.17
312	Soil	Brown	11.49	18.35	25.01	17.87	23.45	2.90	.32	.34	.45	.08	.24	.38	.22	.27
313	Do	Red	8.69	11.17	21.28	38.25	11.98	4.80	.18	.74	1.64	.31	.69	.76	.29	.31
314	Subsoil	do	8.74	10.55	24.66	35.94	12.04	5.00	.04	.58	1.51	.23	.49	.66	.27	.25
315	Soil	do	8.76	17.34	25.38	19.02	23.17	5.00	.23	.43	.54	.11	.31	.53	.24	.26
316	Subsoil	do	6.69	16.79	30.75	19.57	21.86	3.40	.06	.35	.47	.18	.06	.54	.25	.21
317	Soil	Black	11.95	16.42	28.90	20.54	17.30	3.50	.06	.57	.51	.23	.06	.28	.31	.30
318	Subsoil	do	13.92	15.49	27.77	18.84	18.22	4.00	.05	.46	.51	.24	.06	.42	.24	.29
	Kaneohe:															
343	Soil	do	9.38	12.58	45.47	10.21	18.39	2.04	.46	1.11	.79	.09	.33	.18	.03	.18
344	Subsoil	do	11.35	10.87	45.21	9.29	18.73	2.10	.46	1.44	.65	.13	.34	.20	.03	.15
	Kailua coconut plantation:															
335	Soil	White	38.18		6.71	.65	.23	.00	.00	50.05	2.67	.20	.60	.27	.44	.16
336	Subsoil	do	40.45		3.86	.36	.38	.00	.00	50.92	2.69	.20	.60	.08	.46	.06
	Kailua:															
337	Soil	Brown	8.67	17.00	37.02	17.32	13.64	2.22	.08	.69	.75	.24	.41	.69	.24	.40
338	Subsoil	do	10.74	16.46	38.12	17.62	12.97	1.90	.24	.53	.44	.14	.41	.61	.23	.38
339	Soil	do	8.90	19.15	33.75	22.69	11.60	2.66	.07	.39	.24	.13	.40	.26	.18	.37
340	Subsoil	do	10.86	16.41	34.14	23.29	11.08	2.50	.10	.42	.28	.05	.33	.20	.18	.27

510	Soil	do	7.57	15.74	41.86	12.00	18.25	3.20	.18	.41	.98	.26	.60	.24	.50	....
511	Subsoil	do	9.04	14.26	40.93	11.12	17.33	4.00	.14	.47	1.02	.18	.62	.25	.54	....
512	Soil	do	9.04	14.49	41.23	11.64	19.03	3.40	.12	.46	1.06	.18	.44	.23	.50	....
513	Subsoil	do	9.69	16.81	39.49	10.28	19.07	3.20	.06	.48	1.04	.20	.54	.23	.46	....
	Kaelepulu:															
491	Soil	Red	6.74	11.89	26.04	28.12	9.70	2.40	.28	1.46	9.94	.74	.34	1.72	.58	.16
492	Subsoil	do	10.71	7.26	35.04	15.12	12.70	3.80	.22	3.48	8.90	1.50	.56	.50	.58	.02
223	Soil	Gray	1.16	41.85	3.20	.93	.00	....	.96	49.46	1.90	.26	.39	.39	.82	.19
	Kawailoa:															
224	Soil	Red	6.01	26.39	23.38	16.88	9.98	....	.00	13.96	1.56	.50	.04	1.32	.64	.60
225	Do	Brown	7.72	8.37	55.89	12.98	11.65	....	.05	1.27	1.83	.34	.13	.12	.25	.12
226	Do	Red	6.44	11.22	45.90	19.84	14.06	....	.11	1.05	1.16	.42	.15	.05	.20	.15
227	Do	White	.36	40.66	2.60	.21	.00	....	.00	51.74	2.90	.31	.46	.21	.55	.04
228	Subsoil	Blue	.42	40.90	3.08	.29	.00	....	.00	50.78	2.91	.32	.45	.24	.61	.03
	Maunawili:															
341	Soil	Brown	9.65	16.43	17.69	27.00	25.50	2.21	.04	.40	.77	.27	.26	.69	.29	.15
342	Subsoil	do	10.59	17.37	16.54	28.16	22.16	2.90	.14	.28	1.06	.33	.65	.84	.33	.31

TABLE II.—*Humus, humus ash, and total nitrogen in Hawaiian soils.*

Soil No.	Location.	Humus.	Humus ash.	Total nitrogen.
	HAWAII.			
	Puuanahulu:	*Per ct.*	*Per ct.*	*Per ct.*
326	1,300-foot level	6.49	1.19	0.33
327	1,400-foot level	3.08	1.44	.26
328	1,500-foot level	7.01	1.71	.27
	Parker ranch, Waimea:			
474	Soil	7.96	3.65	.65
475	Subsoil	6.50	2.90	.60
468	Parker ranch, Makahalau	9.64	3.32	.64
74	Parker ranch, Waikii	5.54	1.33	.41
75	Do	4.06	1.62	.23
76	Do	3.51	1.46	.18
448	Hilo	3.10	1.24	.49
428	Glenwood	12.32	3.32	.74
221	Do	11.30	2.20	.55
	Pahala, 3,000-foot level:			
497	Soil	6.96	....	.36
498	Subsoil	5.74	2.35	.24
	Honaunau:			
422	460-foot level	16.36	3.90	1.68
423	Subsoil	10.32	4.15	.81
418	760-foot level	3.98	2.40	.41
419	Subsoil	3.22	2.82	.31
	Kiilae:			
437	2,050-foot level	25.52	4.20	2.13
438	Subsoil	14.76	6.52	.61
439	2,700-foot level	14.56	2.58	.74
	KAUAI.			
	Makaweli:			
493	Soil	3.35	.90	.28
494	Subsoil	2.38	1.96	.09
	Kekaha:			
495	Soil	2.80	1.90	.01
496	Subsoil	1.65	1.10	.10
117	Hanapepe	4.60	2.44	.23
	Kauai Fruit & Land Co.:			
429	Soil	4.28	1.29	.30
430	Subsoil	2.54	1.06	.16
207	Homestead	2.89	.71	.36
	Kapaa:			
426	Soil	4.41	1.36	.29
427	Subsoil	3.71	1.36	.16
211	Kilauea	4.71	1.04	.31
463	Hanalei	2.55	1.39	.16
467	Do	2.56	1.42	.15
	MAUI.			
60	Haiku	3.61	....	.27
544	Do	4.27	.98	.26
545	Do	3.92	1.10	.32
551	Do	4.16	1.31	.28
552	Do	4.25	1.00	.27
557	Do	4.56	1.06	.34
558	Do	5.21	2.11	.30
69	Nahiku	19.13	6.33	1.32
	Kaupo, Omsted place:			
525	Soil	6.70	1.92	....
526	Subsoil	4.29	1.81	....
61	Kula, Dowdle field	6.72	1.03	.52
	Ulupalakua ranch:			
377	Soil	2.34	1.04	.31
378	Subsoil	2.76	1.10	.27
	Kamaole Church:			
381	Soil	2.92	1.02	.49
382	Subsoil	1.25	.65	.38
	MAUI—continued.			
	Honolua:	*Per ct.*	*Per ct.*	*Per ct.*
363	650-foot level	3.90	3.10	.29
364	Subsoil	1.43	.97	.14
365	850-foot level	3.88	1.25	.36
366	Subsoil	2.42	1.25	.15
	MOLOKAI.			
	Naiwa district.			
	1,500-foot level:			
349	Soil	3.37	1.13	.24
350	Subsoil	4.64	2.86	.19
	860-foot level:			
353	Soil	1.65	.71	.18
354	Subsoil	1.28	.86	.13
	380-foot level:			
357	Soil	.94	.46	.08
358	Subsoil	.98	.68	.08
	30-foot level:			
359	Soil	2.20	.84	.25
360	Subsoil	3.76	1.79	.19
	OAHU.			
	Waikiki:			
71	Soil	2.00	....	.16
292	Do	1.49	1.27	.14
293	Subsoil	1.76	1.19	.13
	Experiment station:			
288	Soil	3.06	1.48	.21
289	Subsoil	2.71	1.71	.15
290	Soil	1.66	.36	.19
291	Subsoil	1.55	2.25	.12
	Hawaiian Pineapple Co., Wahiawa:			
7	Soil	3.03	1.60	.32
9	Do	3.18	.54	.18
97	Do	2.64	.54	.23
98	Do	2.81	.75	.23
99	Do	3.84	.57	.24
101	Do	3.61	.78	.22
102	Do	3.37	.70	.25
103	Do	4.74	1.12	.21
104	Do	3.22	.76	.19
100	Subsoil	3.48	.64	.17
19	Thomas Pineapple Co., Wahiawa.	2.98	1.45	.22
282	Leilehua	2.77	1.04	.40
283	Do	1.78	.79	.26
284	Do	2.72	.70	.32
285	Do	2.03	.63	.34
286	Do	3.15	.94	.44
287	Do	3.64	1.38	.38
	Kaneohe:			
300	Soil	5.93	1.46	.35
301	Subsoil	3.49	1.41	.21
	Heeia:			
302	Soil	9.65	2.31	.53
303	Subsoil	3.10	1.66	.20
304	Soil	2.74	.61	.24
305	Subsoil	2.88	.66	.24
	Kaneohe:			
306	Soil	3.86	1.36	.32
307	Subsoil	4.99	1.42	.28
308	Soil	4.06	1.03	.31
309	Subsoil	3.14	.83	.29
310	Soil	4.99	1.26	.22
311	Subsoil	4.18	1.00	.17
	Maunawili:			
341	Soil	3.44	1.38	.15
342	Subsoil	4.13	1.25	.31

TABLE III.—*Mechanical composition of Hawaiian soils.*

Soil No.	Location.	Volatile matter.	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Fine silt.	Clay.
	HAWAII.							
	Kohala district.							
	Puuanahulu:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
326	1,300-foot level	17.15	0.22	0.58	22.48	19.28	28.64	13.54
327	1,400-foot level	18.31	.24	.65	30.46	17.58	20.73	13.26
328	1,500-foot level	17.41	.34	.73	22.86	14.81	25.15	19.94
74	Parker ranch, Waikii	25.83	1.64		38.03	16.22	19.99	2.05
75	Do	21.75	.03	3.48	29.50	18.65	20.75	4.48
76	Do	19.45	.02	2.14	26.70	22.90	24.45	3.55
573	Do	23.30	1.71		36.20	21.82	13.60	3.75
	Hilo district.							
448	Hilo	32.95	1.94	8.60	16.31	13.45	20.00	6.85
	Olaa district.							
428	Glenwood	29.85	13.81	32.82	15.83	5.38	1.76	.69
	Kona district.							
111	Keahui	22.65	.00	14.42	32.15	12.65	14.17	5.38
112	Do	32.70	.07	3.22	17.60	15.70	24.50	6.58
113	Do	33.60	.12	2.49	15.23	13.62	25.80	7.10
	Hanauhau:							
422	460-foot level	43.50	1.66	1.87	26.29	16.03	10.33	1.07
423	Subsoil	26.97	1.97	2.98	36.75	21.63	9.19	.99
420	510-foot level	22.93	2.17	2.26	16.62	17.46	31.88	7.16
421	Subsoil	19.12	.49	1.29	16.31	14.07	35.48	14.03
424	680-foot level	20.30	3.18	3.99	22.15	21.63	23.61	3.98
425	Subsoil	16.87	3.95	5.15	22.02	19.58	25.76	6.29
418	760-foot level	17.95	3.10	3.04	20.72	21.04	27.65	6.67
419	Subsoil	13.42	5.25	5.10	19.43	19.19	28.52	9.09
	KAUAI.							
	Kona district.							
116	Hanapepe	18.75	.02	1.57	5.48	6.49	33.40	35.50
117	Do	19.90	.10	3.11	7.58	7.22	36.50	27.40
118	Do	15.60	1.23		11.78	11.65	24.20	35.80
119	Do	13.74	.34		5.72	4.65	33.20	43.70
120	Do	17.85	1.45		4.17	4.43	34.20	39.10
	Koloa:							
373	Soil	21.41	.10	.40	9.66	12.78	29.01	27.24
374	Subsoil	16.42	.06	.12	11.88	9.04	22.28	41.09
375	Soil	25.28	.24	.42	18.35	10.31	32.45	15.04
376	Subsoil	19.21	.12	.45	26.89	13.37	20.69	20.92
	MAUI.							
	Hamakuapoko district.							
61	Haiku	25.16	.12	7.20	40.90	9.85	15.01	2.93
	Koolau district.							
69	Nahiku	44.60	5.94	26.72	8.65	4.07	5.09	5.78
	Kula district.							
	Alexander field:							
105	Soil	11.59	0.98		20.40	9.53	35.80	22.55
109	Subsoil	14.80	0.53		5.71	5.62	11.55	64.10
106	Soil	12.00	1.12		20.40	9.26	36.30	21.85
108	Subsoil	15.55	0.96		13.58	6.25	13.35	51.26
	Dowdle field:							
107	Soil	10.57	1.21		21.21	10.63	39.88	15.87
110	Subsoil	14.92	0.92		5.18	7.77	17.20	54.30
	Kaanapali district.							
	Honolua:							
361	450-foot level	16.22	.64	.94	39.51	16.02	9.73	17.36
362	Subsoil	13.09	.08	.12	14.47	10.84	26.43	35.57
363	650-foot level	16.11	.43	.68	19.79	17.59	26.51	19.39
364	Subsoil	13.32	.05	.24	13.09	11.63	29.11	33.32
365	850-foot level	16.46	.01	1.90	11.64	20.89	37.95	13.89
366	Subsoil	17.22	.07	.15	4.02	7.11	18.64	54.11

TABLE III.—*Mechanical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Volatile matter.	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Fine silt.	Clay.
	MOLOKAI.							
	Naiwa district.							
	1,500-foot level:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
349	Soil	10.71	0.46	1.00	22.05	12.34	45.95	8.91
350	Subsoil	16.38	.03	.24	9.80	8.99	27.20	39.70
	1,050-foot level:							
351	Soil	9.06	.08	.36	13.89	20.32	45.99	10.98
352	Subsoil	13.18	.01	.16	11.41	9.09	24.99	43.23
	860-foot level:							
353	Soil	15.24	.03	.41	35.86	18.59	18.78	12.09
354	Subsoil	13.54	.05	.54	30.67	20.49	19.05	16.10
	600-foot level:							
355	Soil	13.05	.01	.73	36.15	14.89	19.47	15.85
356	Subsoil	12.48	.00	.86	40.41	15.35	18.06	14.22
	380-foot level:							
357	Soil	12.95	.03	.23	39.84	17.72	14.40	14.97
358	Subsoil	12.98	.00	.15	40.54	14.96	13.67	17.75
	30-foot level:							
359	Soil	15.39	.25	.55	44.65	21.98	9.91	7.45
360	Subsoil	17.82	.00	.13	48.13	23.73	6.59	3.96
	OAHU.							
	Kona district.							
	Waikiki:							
292	Soil	8.71	20.91	18.75	22.04	8.69	12.41	7.23
293	Subsoil	10.77	18.61	18.30	22.74	8.10	13.48	9.52
	Experiment station:							
288	Soil	14.42	.85	7.92	16.19	10.94	25.31	24.89
289	Subsoil	13.82	.56	6.16	8.89	6.96	24.07	40.35
290	Soil	16.22	.14	.58	7.77	9.33	18.14	48.35
291	Subsoil	14.37	.00	.39	7.40	7.28	12.13	59.35
	Kalihi:							
332	Soil	14.37	1.15	1.61	18.34	16.28	23.88	25.37
333	Subsoil	14.05	1.02	1.28	20.63	17.88	22.11	24.06
334	Soil	15.23	.62	1.63	15.33	15.77	21.73	31.61
	Waipio district.							
114	Hawaiian Pineapple Co.	16.60	.04	1.62	8.94	9.08	31.35	32.20
	Wahiawa district.							
	Hawaiian Pineapple Co:							
7	Soil	13.14	.00	.77	3.64	8.85	34.54	36.28
9	Do	16.77	.87	8.20	22.44	13.94	23.13	13.11
97	Do	14.32	.09	.43	1.62	3.31	27.19	52.30
98	Do	13.65	.12	.43	2.11	3.06	26.32	55.05
99	Do	15.80	.73	.86	2.35	9.28	32.69	38.60
101	Do	13.06	.14	.50	1.33	6.23	28.88	47.45
102	Do	14.67	.29	.91	1.12	7.38	18.87	57.80
103	Do	17.58	.05	.26	.81	5.60	22.70	56.72
104	Do	16.17	.09	.42	2.36	6.44	29.07	44.54
100	Subsoil	15.55	.41	1.65	1.65	6.72	18.45	57.80
530	Soil	14.41	0.50		5.97	10.74	39.40	28.95
19	Thomas Pineapple Co.	13.35	0.60		2.31	6.79	38.42	37.58
15	Hawaiian Preserving Co.	16.66	2.54	6.28	21.17	14.57	21.90	15.50
516	Do	19.70	3.79	5.90	33.10	11.50	17.56	8.42
574	Do	15.13	1.24	.39	8.71	10.10	26.90	37.70
542	Kunia	19.35	0.88		33.95	14.55	19.34	11.95
282	Leilehua	20.34	.69	2.31	23.44	12.84	23.69	18.45
283	Do	18.88	.80	2.86	23.79	11.75	20.95	22.59
284	Do	21.20	.69	2.41	28.11	11.26	19.86	19.51
285	Do	19.91	.95	2.39	25.62	10.69	22.71	19.37
286	Do	21.11	.34	1.76	24.89	13.13	23.65	16.71
287	Do	20.48	.91	1.80	27.47	11.13	22.96	17.90
	Waialua district.							
331	Helemano	20.43	.01	1.65	45.17	12.86	9.82	11.31
164	Opaeula	3.61	0.17		3.79	19.50	51.70	21.10
115	Do	12.88	0.47		3.72	6.03	45.40	31.80
	Pupuukea:							
49	Soil	14.54	.02	.42	11.65	11.41	46.30	16.77
50	Subsoil	14.15	.04	.23	3.88	6.67	28.46	48.57
51	Soil	16.39	1.98	3.67	19.57	9.16	32.09	19.13
52	Subsoil	13.54	2.16	6.71	11.22	7.43	23.75	36.69

TABLE III.—*Mechanical composition of Hawaiian soils*—Continued.

Soil No.	Location.	Volatile matter.	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Fine silt.	Clay.
	OAHU—Continued.							
	Koolauloa district.							
	Koluanui:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
347	Soil	36.14	0.41	0.83	21.49	27.45	7.61	6.38
348	Subsoil	49.24	.22	.64	11.29	15.27	20.07	6.19
	Koolaupoko district.							
	Waiahole:							
345	Soil	15.04	.15	3.09	25.94	20.97	15.96	19.84
346	Subsoil	15.31	.46	3.59	34.44	19.30	10.96	14.29
319	Heeia	20.31	.11	.54	20.98	18.07	25.31	16.42
	Kaneohe:							
300	Soil	13.94	.75	.59	24.11	14.47	35.03	11.05
301	Subsoil	11.71	.23	.35	31.08	19.13	21.91	15.59
	Wireless Station, Heeia:							
302	Soil	23.71	.23	.48	15.56	17.66	31.42	11.44
303	Subsoil	16.43	.22	.23	5.93	9.42	25.72	42.78
304	Soil	16.14	.17	.42	16.76	16.61	25.47	23.53
305	Subsoil	16.13	.23	.32	12.78	15.51	27.79	26.78
	Koeling's, Kaneohe:							
306	Soil	17.34	.22	.35	10.50	13.03	37.03	22.06
307	Subsoil	19.44	.17	.53	26.64	16.17	28.53	8.76
	Kaneohe:							
308	Soil	19.12	.96	1.10	17.57	14.00	35.86	10.72
309	Subsoil	18.21	.74	.94	17.66	15.97	36.36	10.90
310	Soil	18.53	.19	.54	13.40	19.08	29.24	20.07
311	Subsoil	17.81	.26	.62	10.41	15.09	21.65	32.45
312	Soil	22.42	.21	.96	25.76	13.54	25.19	14.74
313	Do	13.64	.63	1.46	20.90	45.63	11.38	8.34
314	Subsoil	11.95	.35	1.00	24.68	26.08	27.35	7.55
315	Soil	20.69	.32	1.35	23.80	15.21	21.91	19.25
316	Subsoil	17.77	.33	.87	23.79	20.87	17.34	20.04
317	Soil	19.08	.13	.56	12.62	16.82	26.53	25.83
318	Subsoil	19.30	.09	.75	16.14	22.17	24.82	18.17
343	Soil	15.44	.05	.19	16.03	30.79	14.64	20.16
344	Subsoil	13.20	.22	.11	15.29	28.94	20.67	21.73
	Kailua:							
337	Soil	18.72	.35	.69	18.78	13.57	22.92	25.70
338	Subsoil	19.54	.33	.86	18.60	15.97	21.97	23.19
339	Soil	21.17	.13	.22	18.13	20.42	22.37	19.19
340	Subsoil	19.41	.06	.31	16.75	19.27	23.42	22.98
	Maunawili:							
341	Soil	19.39	.27	.96	32.29	20.92	15.64	12.26
342	Subsoil	20.61	.58	1.31	17.90	16.18	34.39	11.37

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